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Forward Detectors in CDF II

Part-II

- Beam Shower Counters
- MiniPlug Calorimeters

Outline

Introduction

Beam Shower Counters

- *Design, Electronics, Signals*
- *Rapidity Gap Triggers*
- *Beam Loss Measurements*

MiniPlug Calorimeters

- *Design, Electronics, Signals*
- *Energy Calibration*
- *Position and Energy Measurements*

Detecting Charged Particles

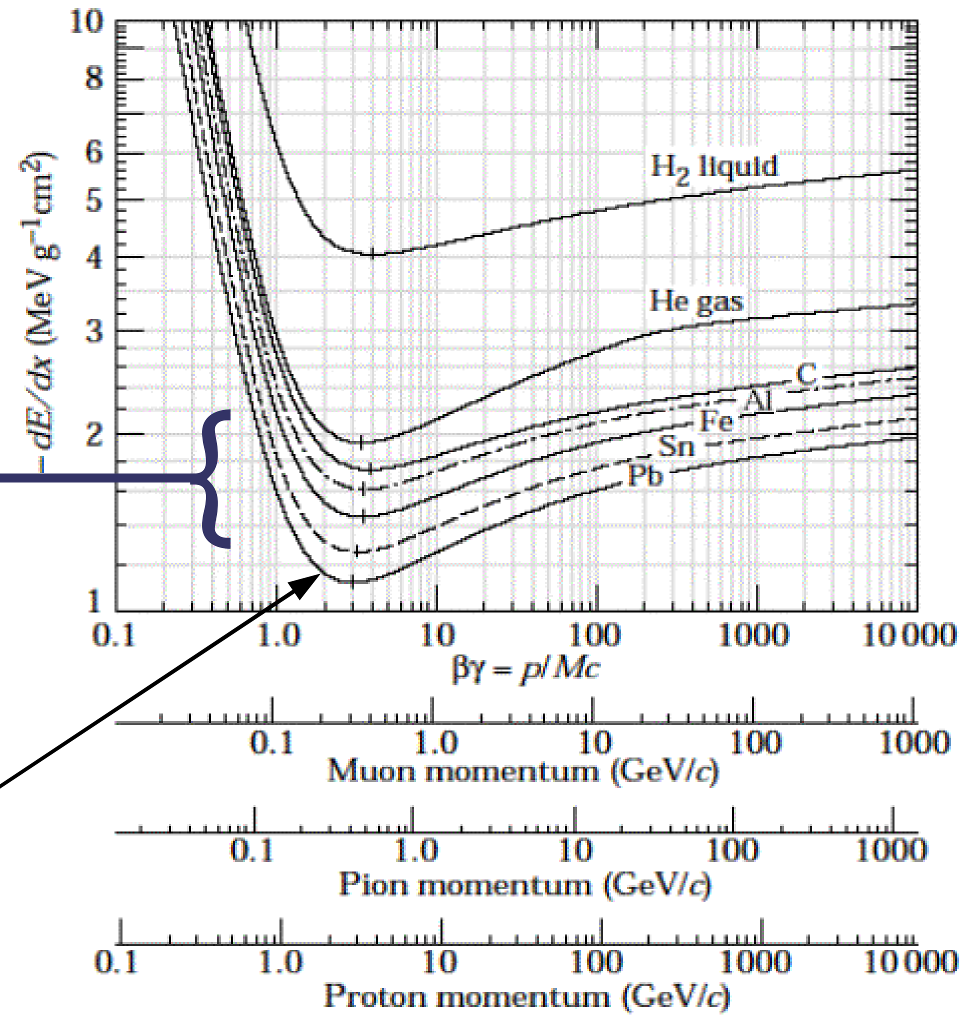
***Mean rate** of energy loss* (Bethe-Bloch formula)

$$-\left\langle \frac{dE}{dx} \right\rangle = Kq^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2 m_e c^2 \gamma^2 \beta^2}{I^2} T_{max} - \beta^2 - \frac{\delta}{2} \right]$$

PDG 2004

- works only for heavy particles
- *dE/dx* in unit of MeV/(g/cm^2)
- function only of β in a given material

similar *dE/dx* for particles with same β in different materials



Minimum Ionizing Particles (MIPs)

Scintillators

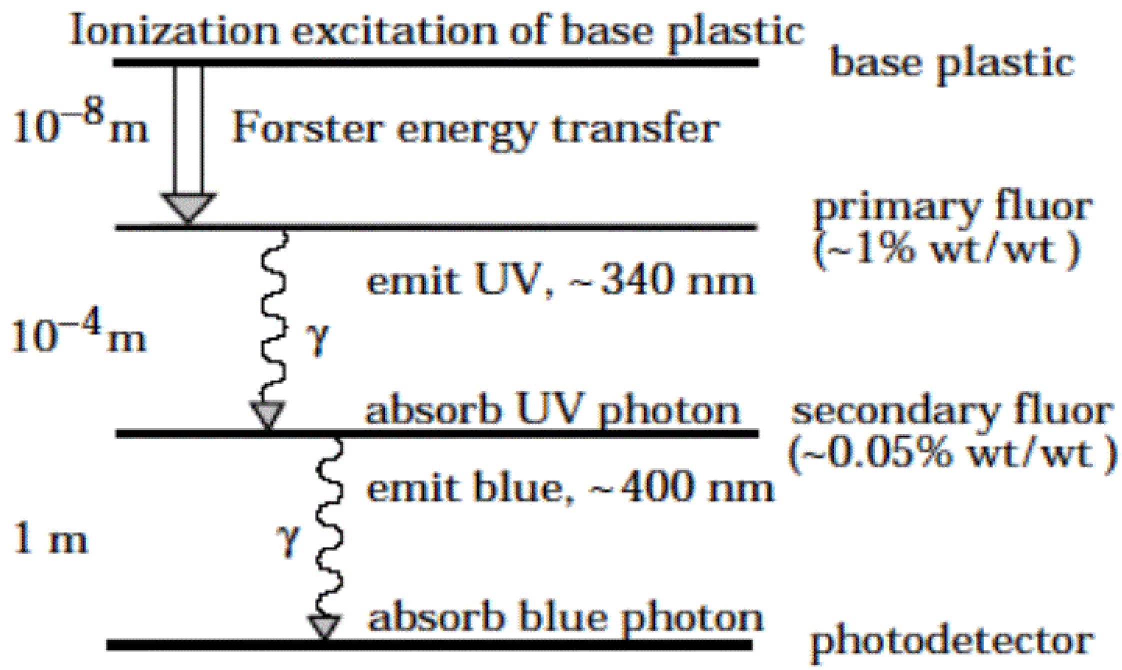
PDG 2004

Organic Scintillator

- excite molecules
- emit UV photons

Fluor

- absorb γ's and re-emit at a longer wavelength (→ wavelength shifting)
- shorten decay time



Scintillator	density (g/cm^3)	τ_{decay} (ns)	λ_{max} (nm)	pulse height (%anthracene)
anthracene	1.25	30-32	448	100
BC-404	1.032	1.8	408	68
BC-517L (MiniPlug)	~ 1.0	2.0	425	30-39
SCSN-81 (BSC)	1.032	2.4	437	55-60

Scintillators

Plastic Scintillator

- $dE/dx|_{mip} \cong 1.95$ MeV/g/cm^2
- density $\cong 1.0$ g/cm^3

➢ Energy Loss $\cong$ 2 MeV/cm

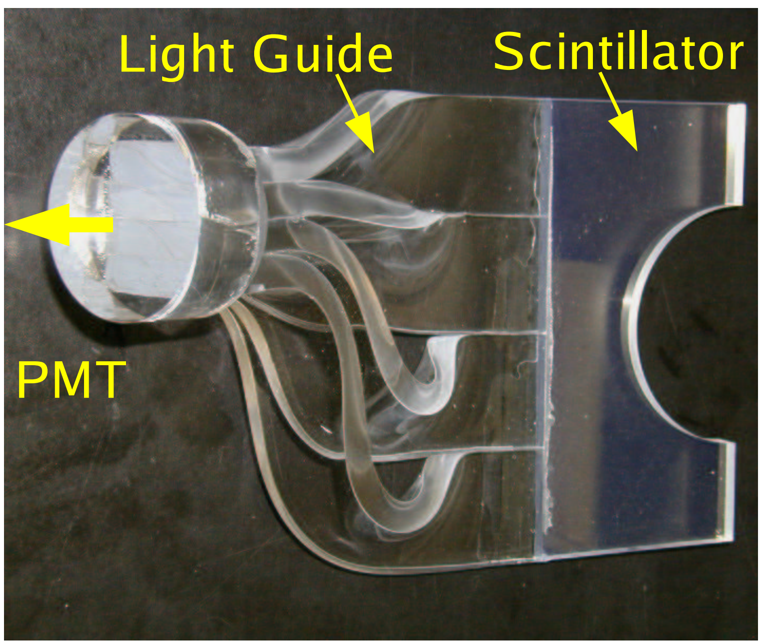
➢ typ. photon yields: ~1/100 eV

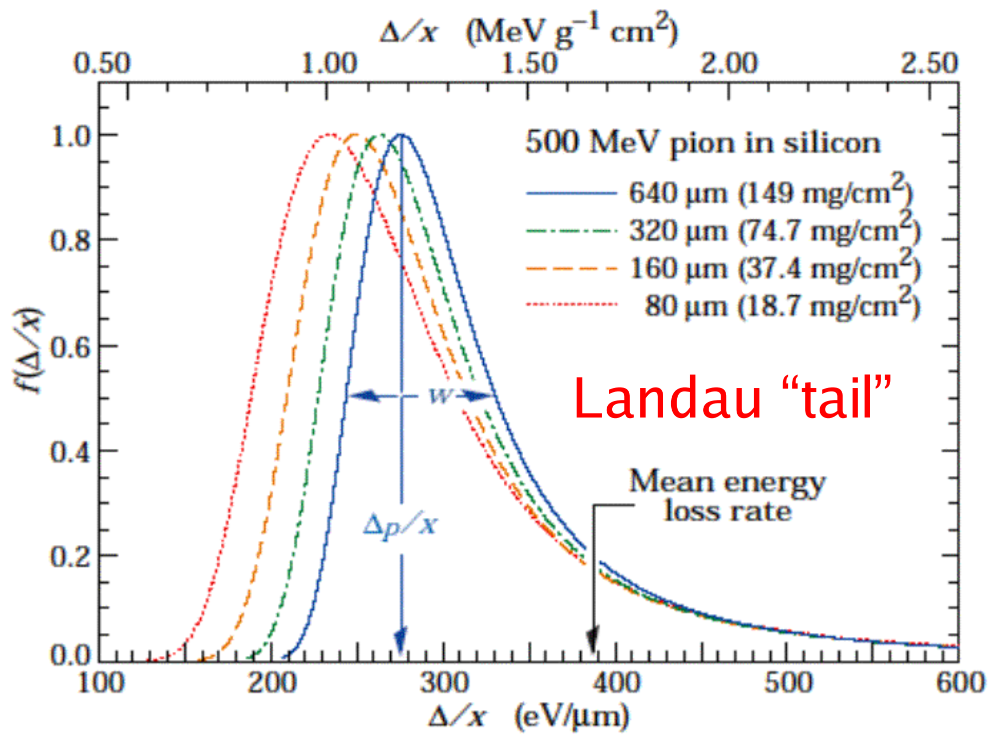
➔ ***~2x10^4 photons /cm***

Actual photons (or photo-electrons) that we detect depend on

✔ collection efficiency (~10%) ➔ ***~2x10^3 photons***

✔ quantum efficiency of photo-cathode (~10%) ➔ ***~2x10^2 pe***



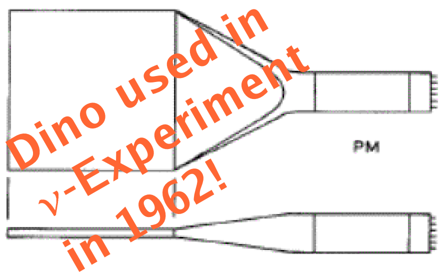


PDG 2004

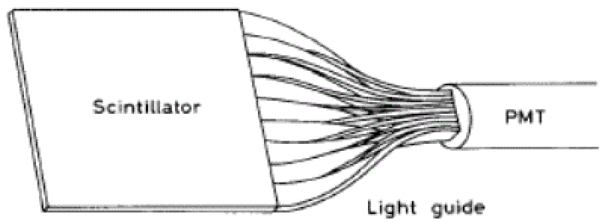
➢ large fluctuations for thin (low density) material

➢ $w \sim \pm 25\%$ of pulse height, independently of x

Scintillator Readout



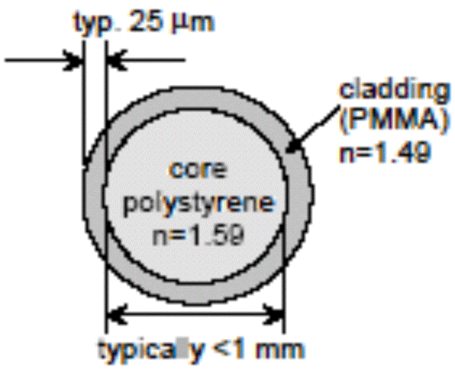
"fish tail"

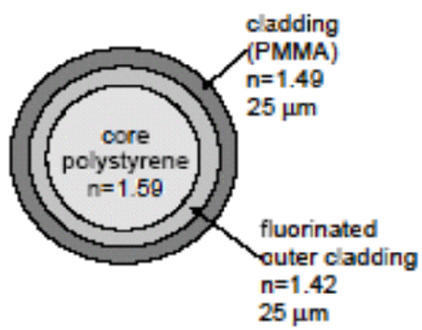


adiabatic

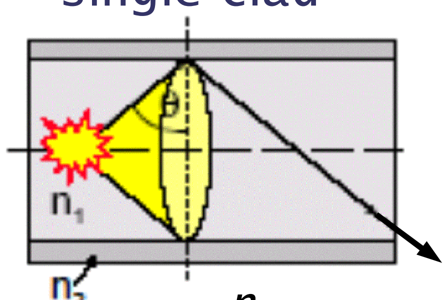
Light Guide (Lucite):

- Transfer by total internal reflection (+ outer reflector)
- Used in BSC : adiabatic



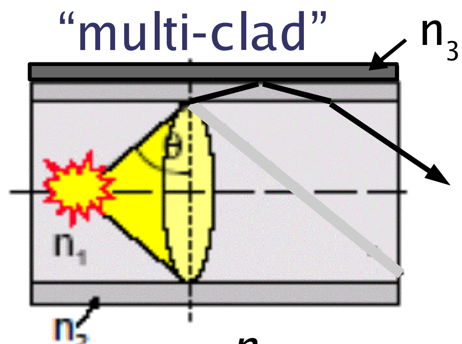


"single-clad"



$$\theta \geq \arcsin\frac{n_2}{n_1} \approx 69.6^o$$

"multi-clad"

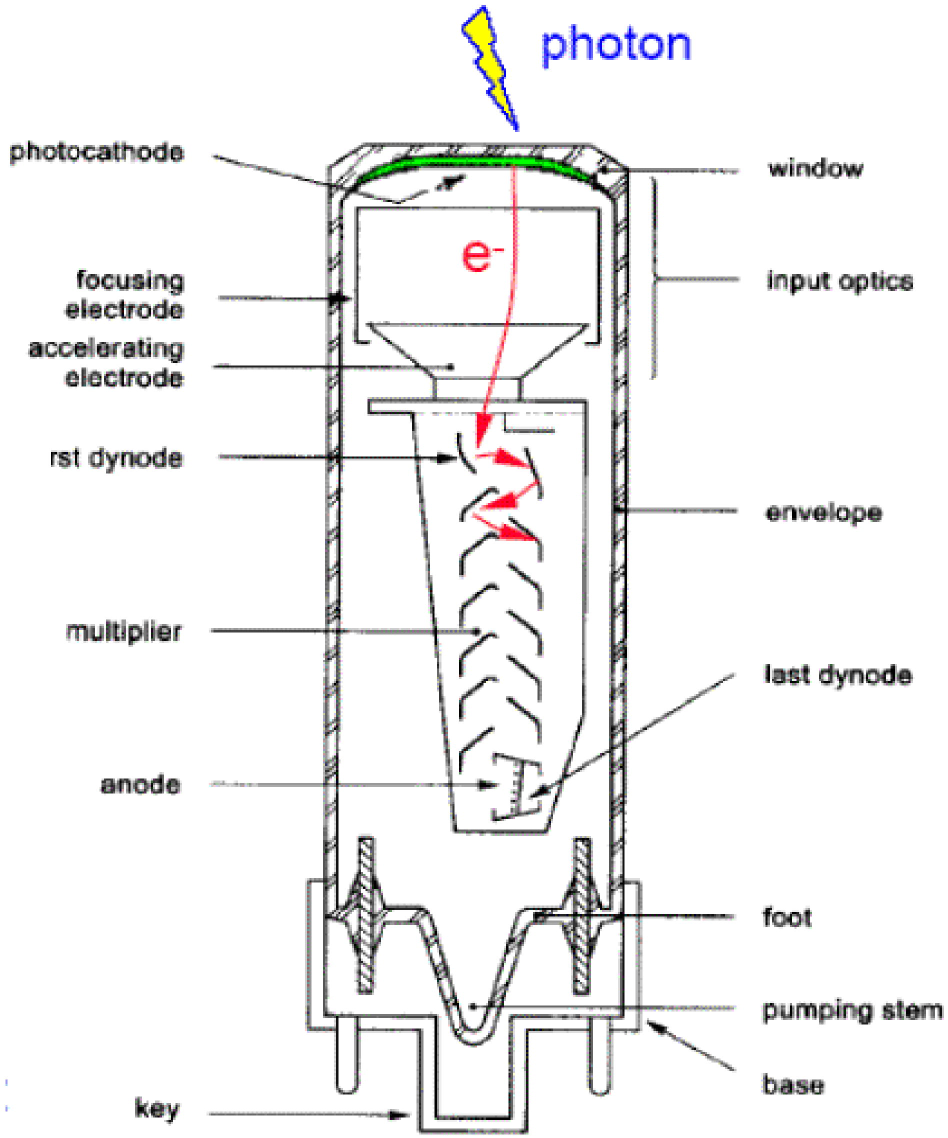


$$\theta \geq \arcsin\frac{n_3}{n_1} \approx 63.3^o$$

Optical Fiber:

- transfer by total internal reflection
- Used in MiniPlug : multi-clad WLS fiber

Photo Multiplier Tube



Convert photons to detectable electric signal

- *photoelectric effect* at photo cathode
- secondary emission from dynodes
- total gain (Πg_{dynode}): typically 10^6

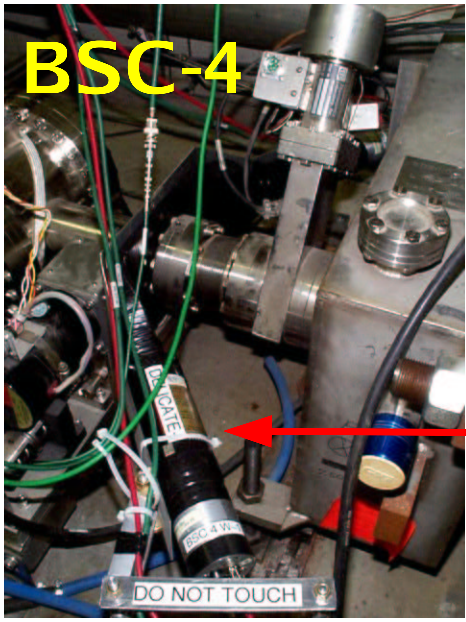
Window:

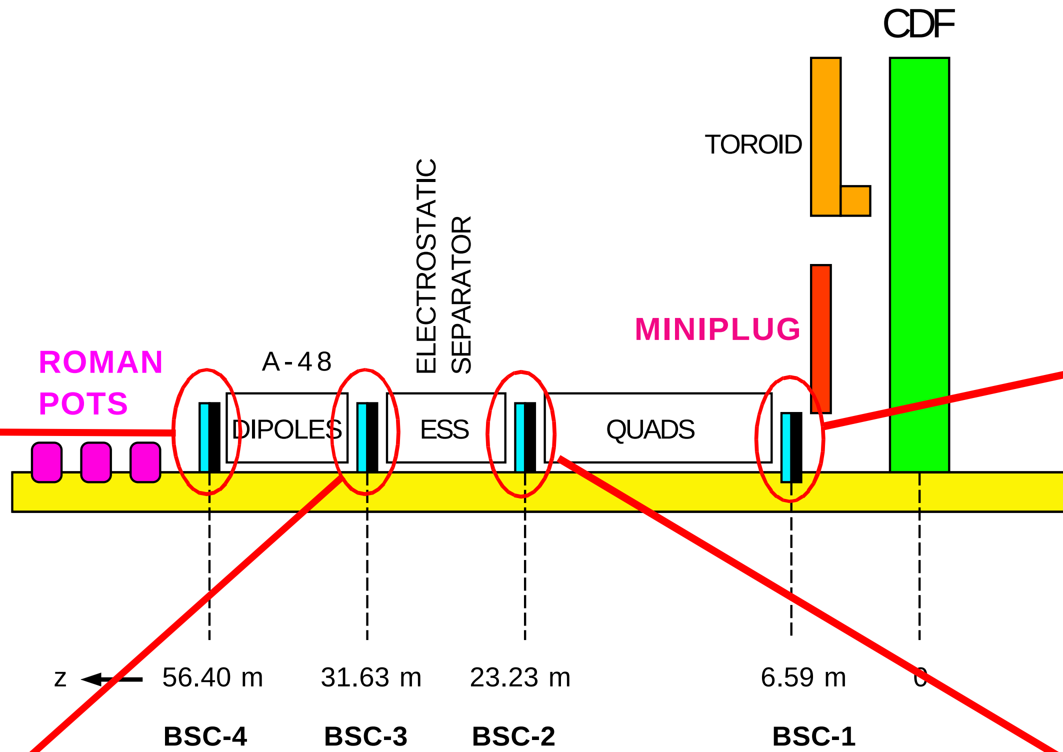
- borosilicate glass (not UV) → BSC
- UV glass
- fused quartz (λ>160 nm) → MiniPlug

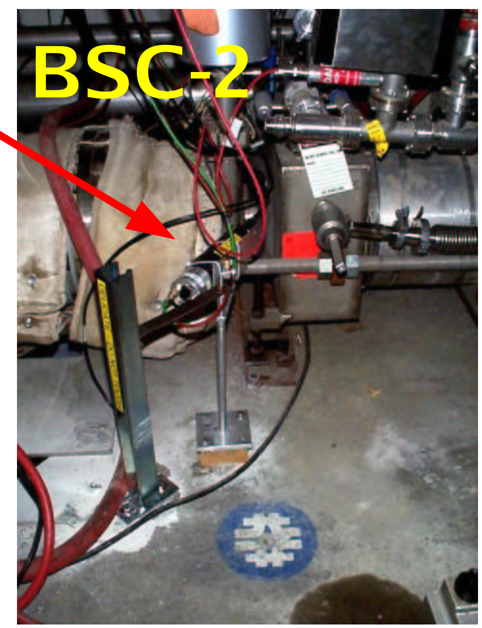
Photo cathode:

- bialkali (Sb-K_2-Cs)
- multialkali (Sb-Na_2-K-Cs)
- Quantum Efficiency Q.E. = $N_{p.e.}/N_{photons}$
  typically 10-20 %

Beam Shower Counters



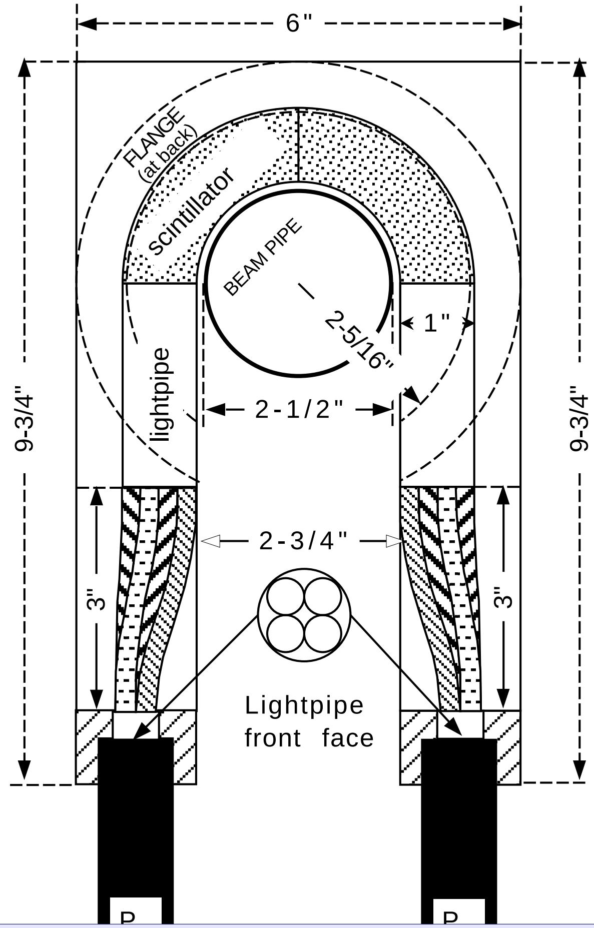


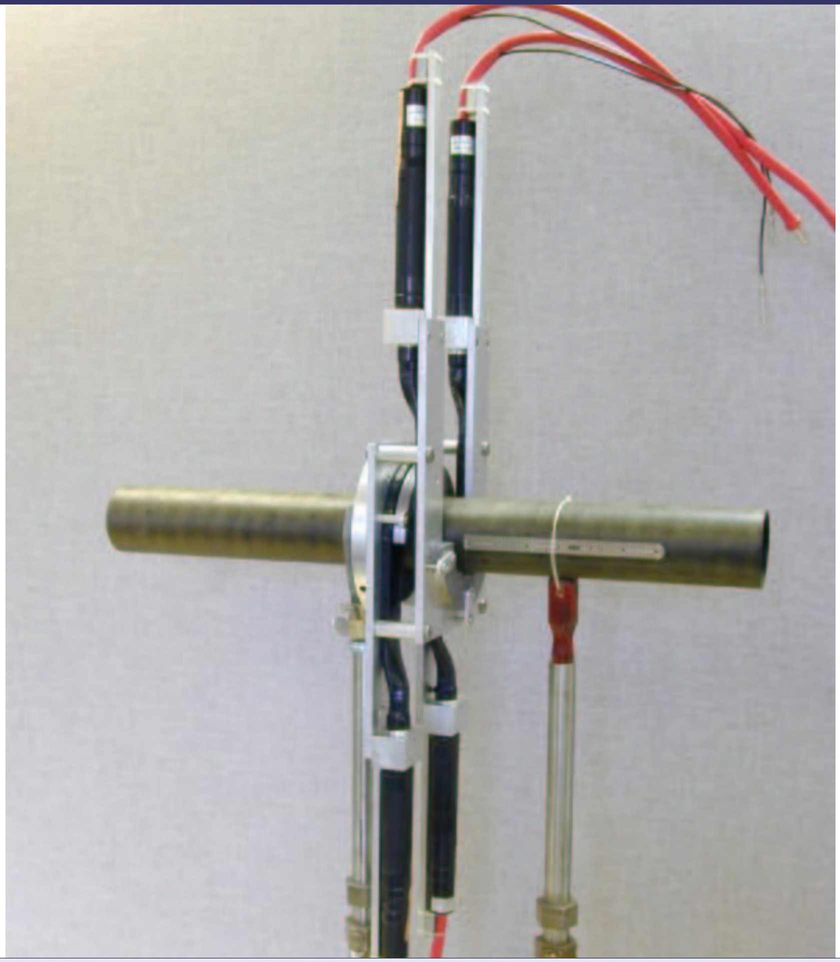


Pbar side : 4 BSC Stations
P side : 3 BSC Stations

$$5.5 < |\eta| < 7.5$$

BSC-1 Design



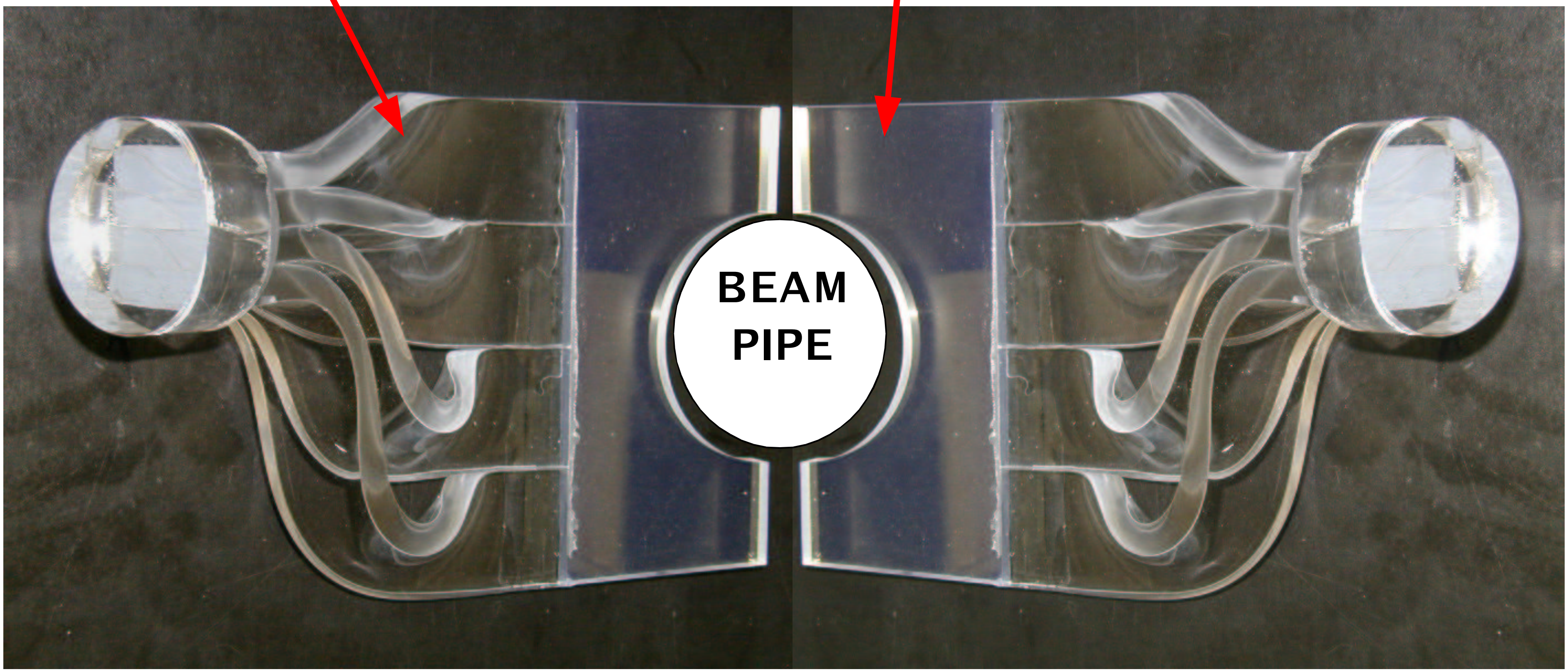


- 6.4mm thick SCSN-81
- 1 scintillator + PMT per 90° segment
- used to measure collision rates and losses
- lead plates attached in front to convert γ's
- scinti. + light guides remade and installed during March shutdown

BSC-2/3/4 Design

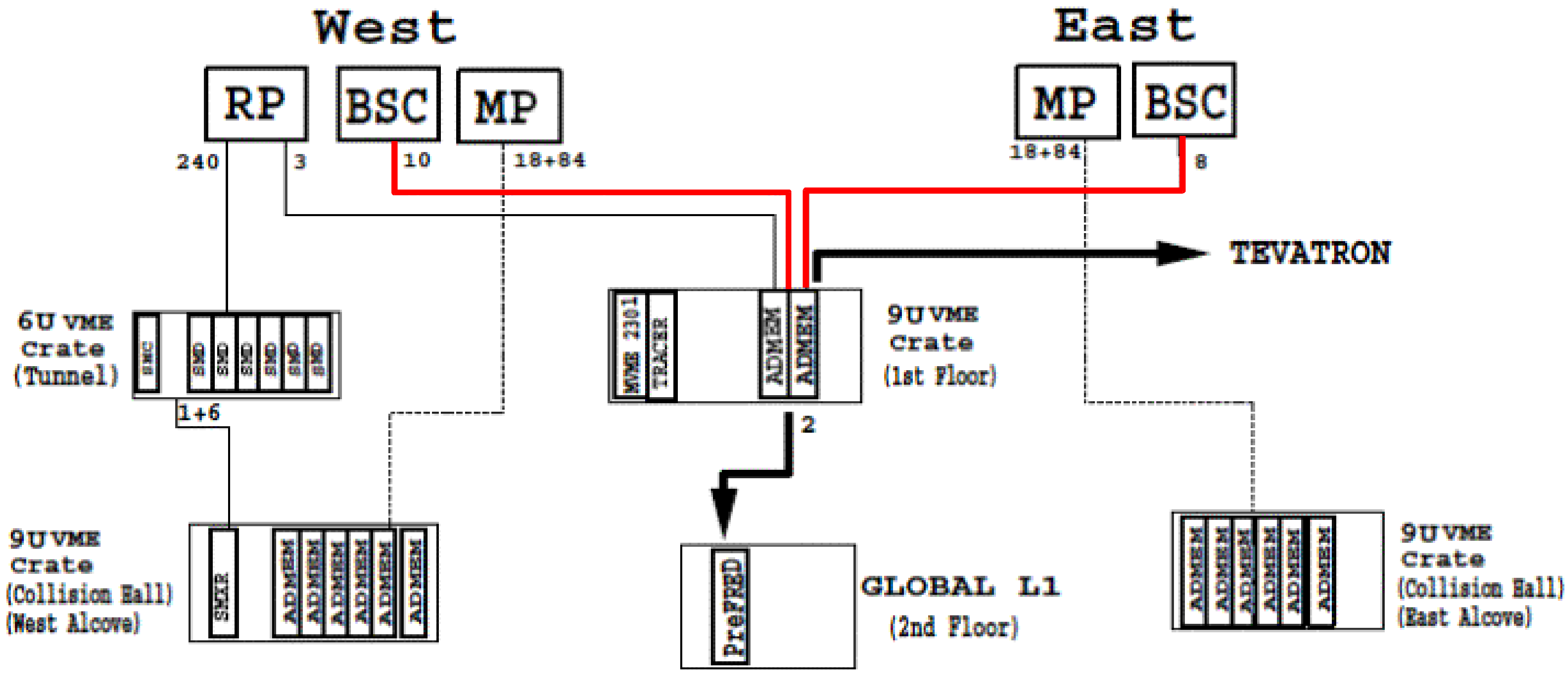
Light Guide

Scintillator



- 9.0mm thick SCSN-81
- 1 scintillator + PMT per side
- used as veto to trigger on gaps
- scinti. + light guides remade and installed during this shutdown

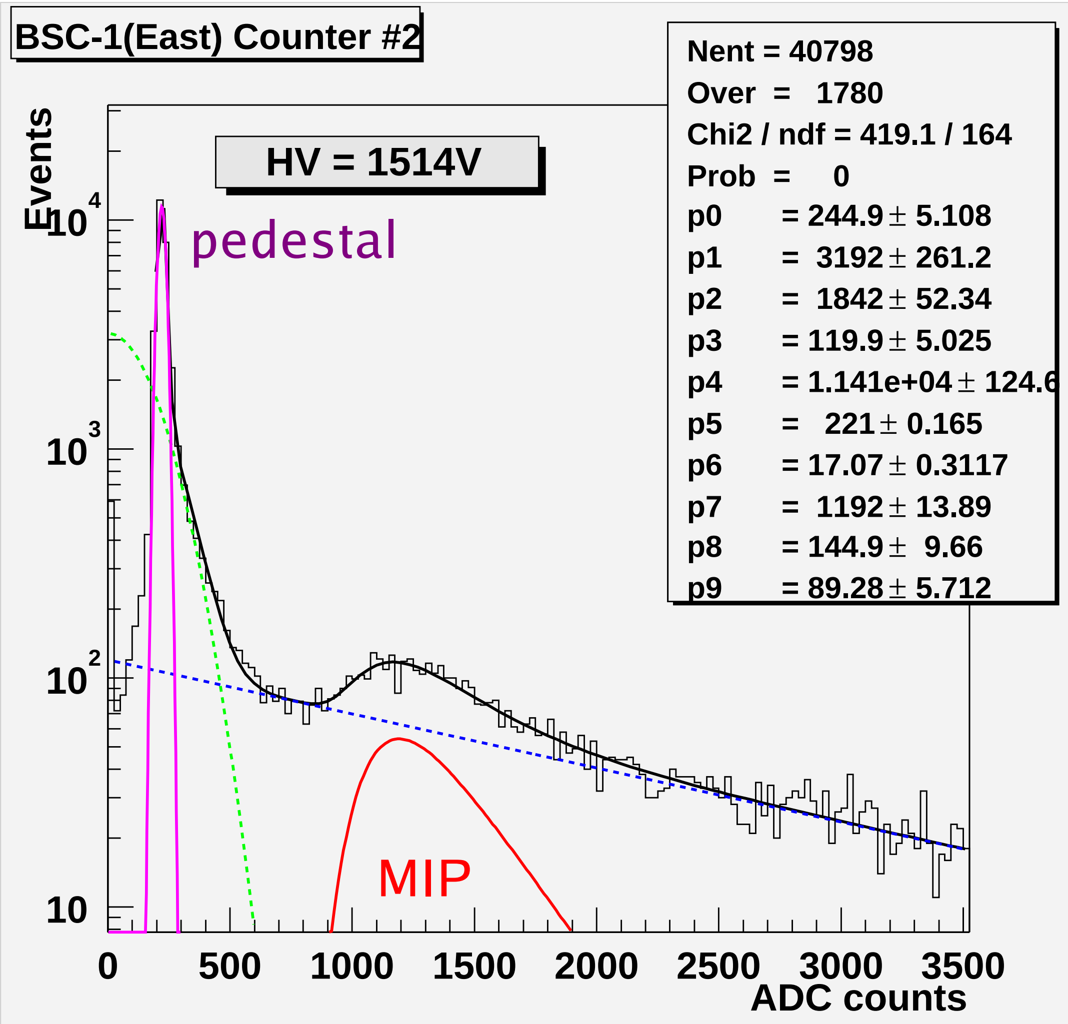
Readout Electronics



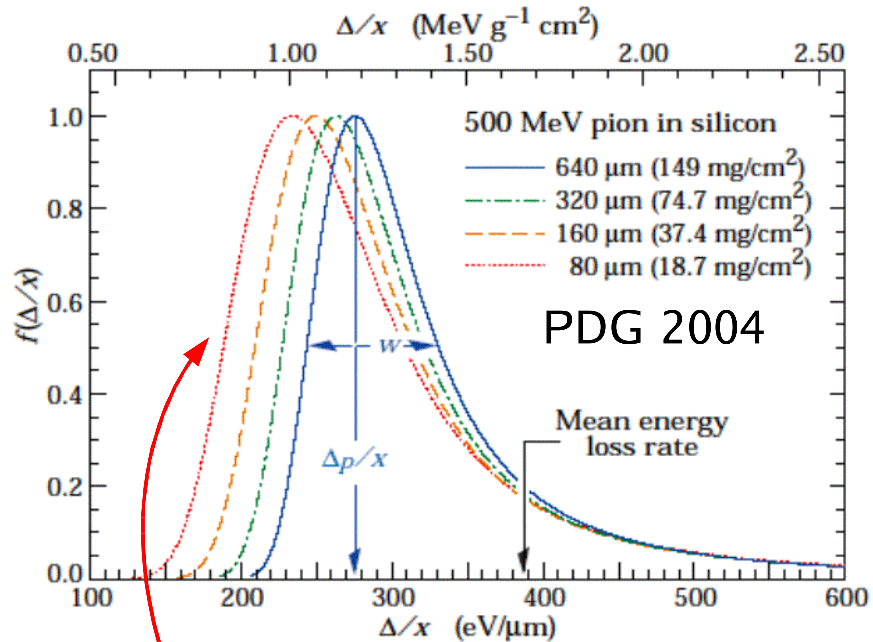
18 PMT signals delivered to 2 ADC/Memory Modules (ADMEM) in CLC_00 VME crate on the first floor

3 RP trigger counter PMT signals also sent to one of the ADMEMs

Digitized Signal



Minimum ionizing particle peak well approximated by Landau distribution

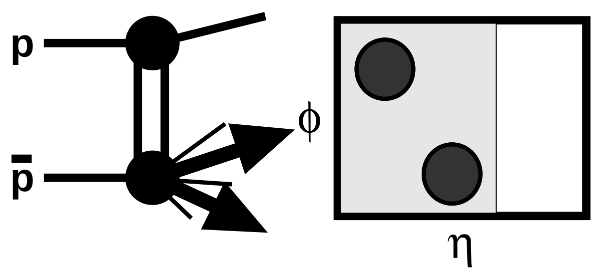


- large fluctuations for thin (low density) material
- Actual energy loss (Δ_p/x) in a detector is smaller than mean energy loss from Bethe-Bloch formula (e.g, <70% in Si)

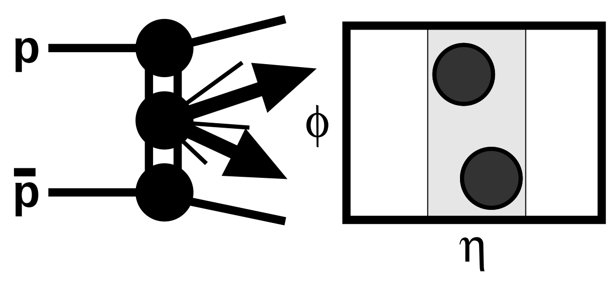
Rapidity Gap Trigger

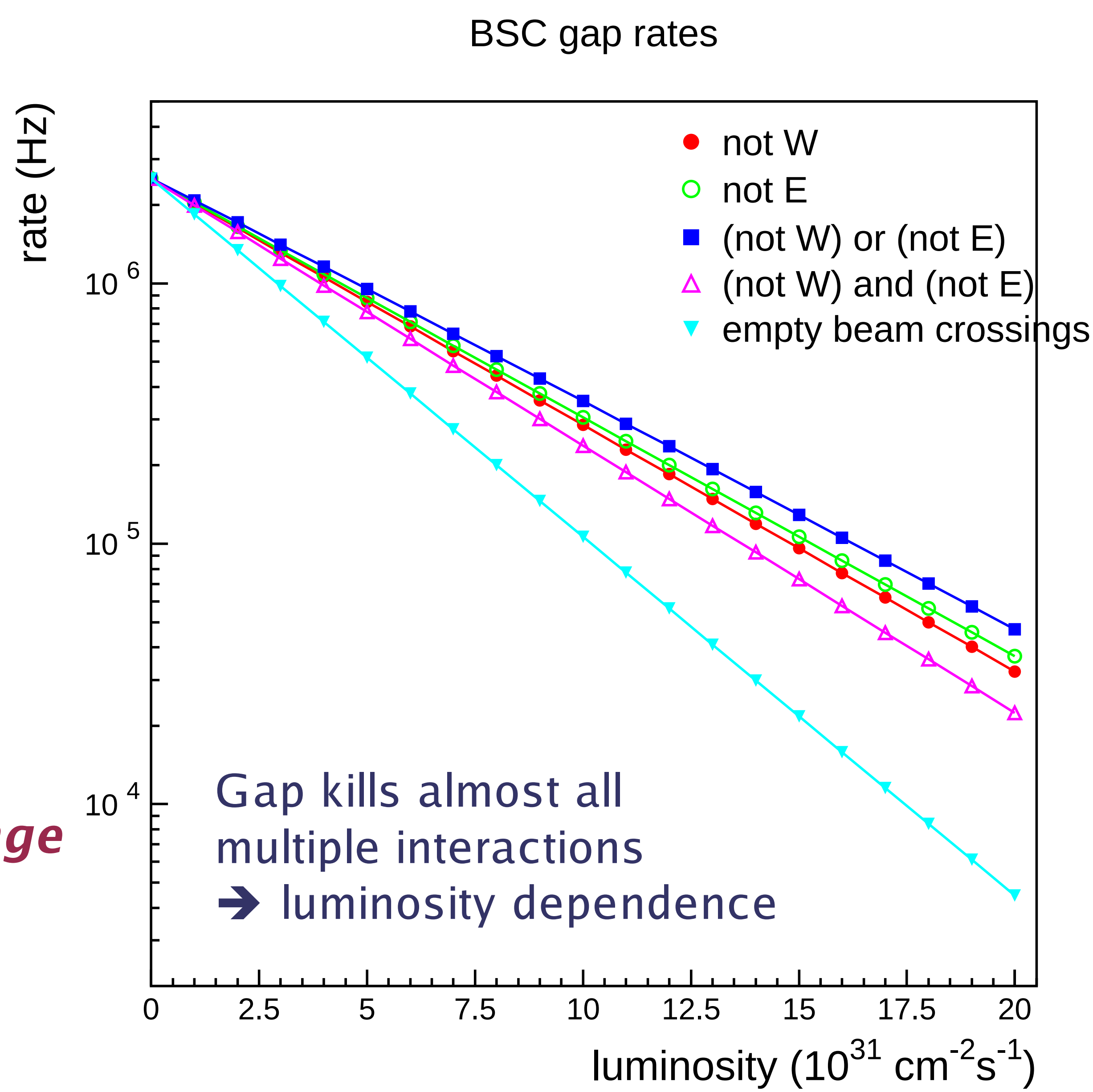
Require BSC veto (gap)
- reject ≥95% of non-diffractive events
- retain ≥95% of diffractive events with $\xi<0.1$

One-side gap
➔ ***Single Diffraction***



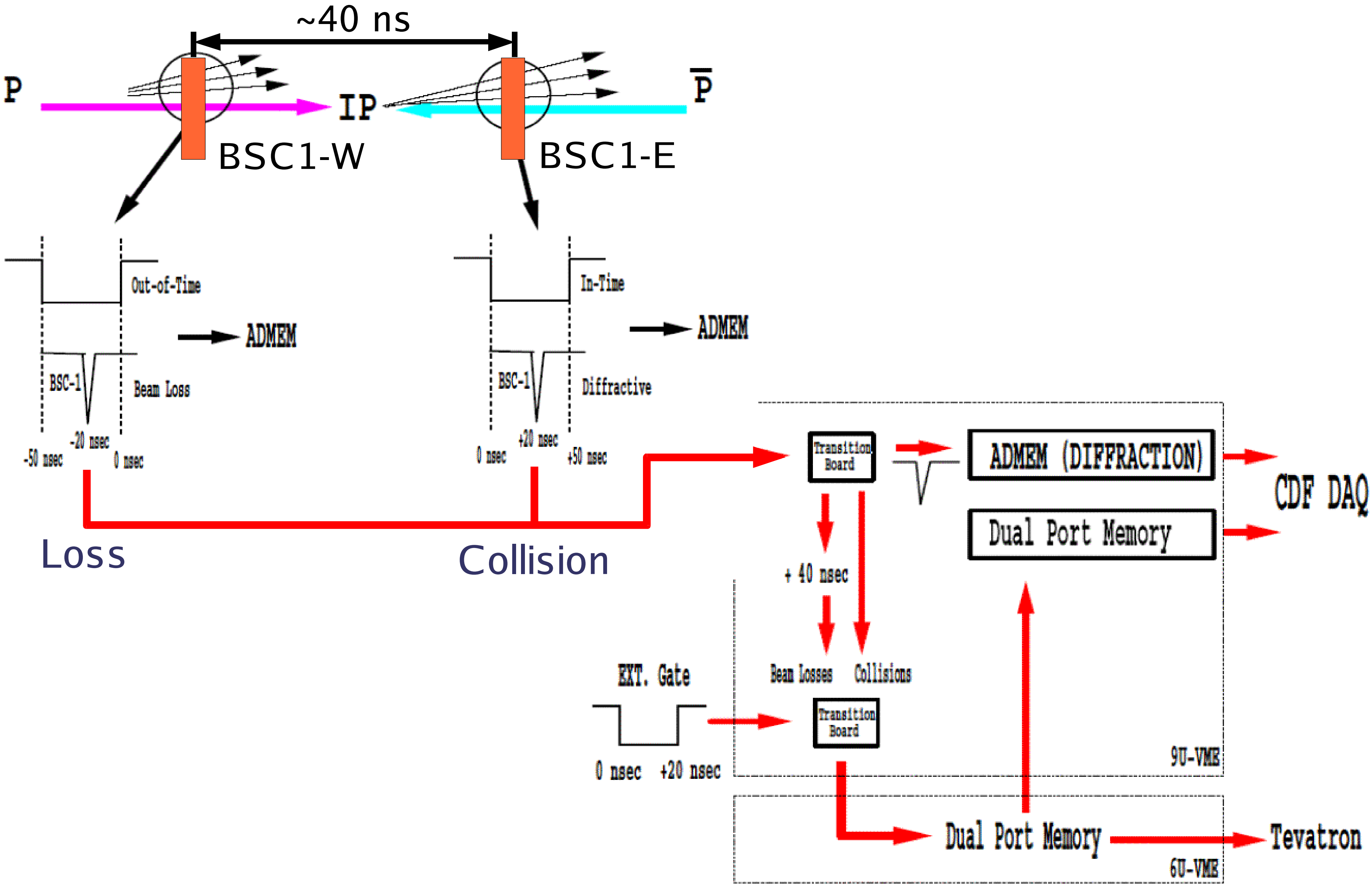
Double-side gap
➔ ***Double Pomeron Exchange***





Gap kills almost all multiple interactions
➔ luminosity dependence

Beam Loss Measurements



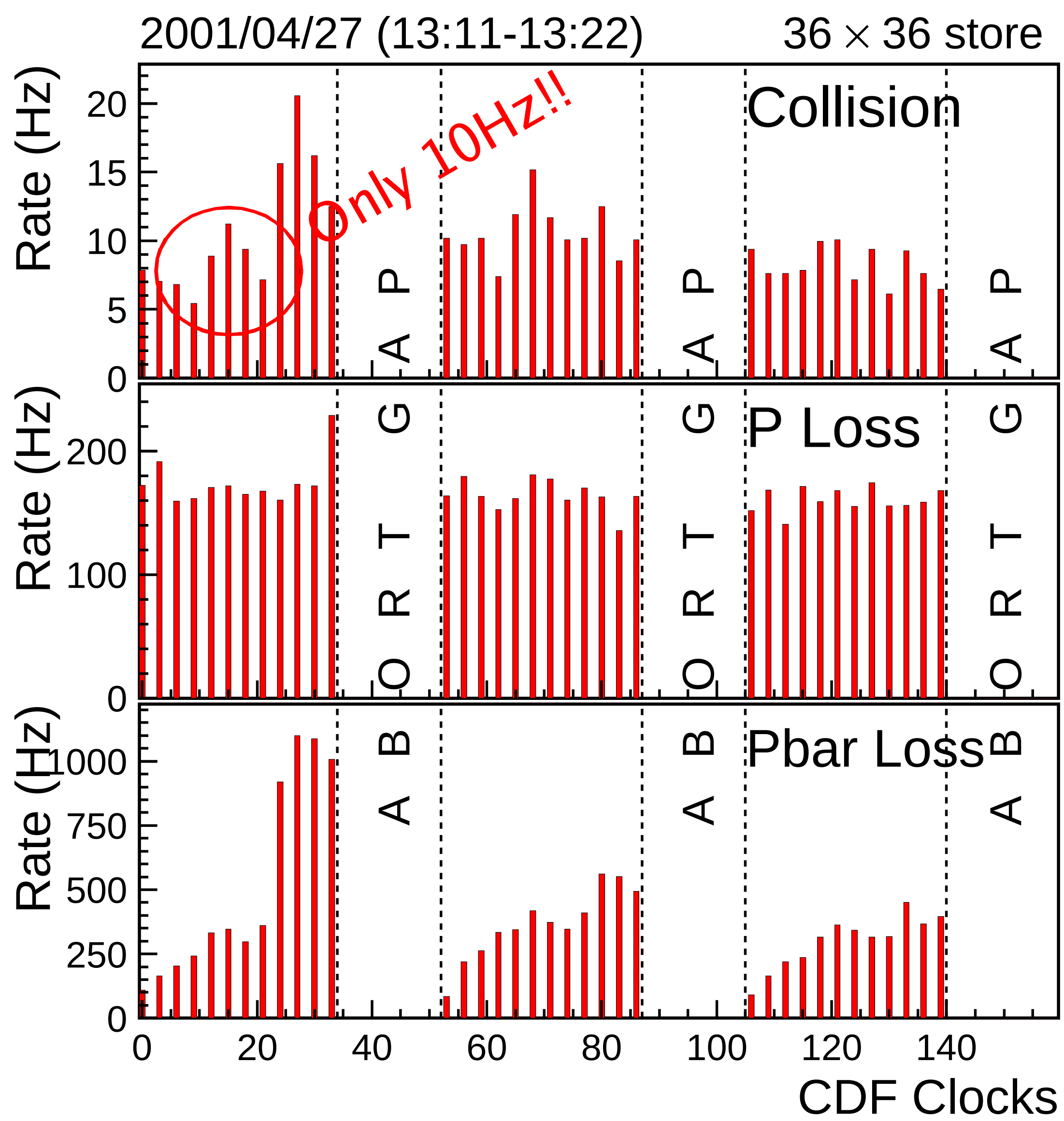
Beam Loss Measurements

Send total and bunch-by-bunch losses to Accelerator Division (since beginning of Run II)

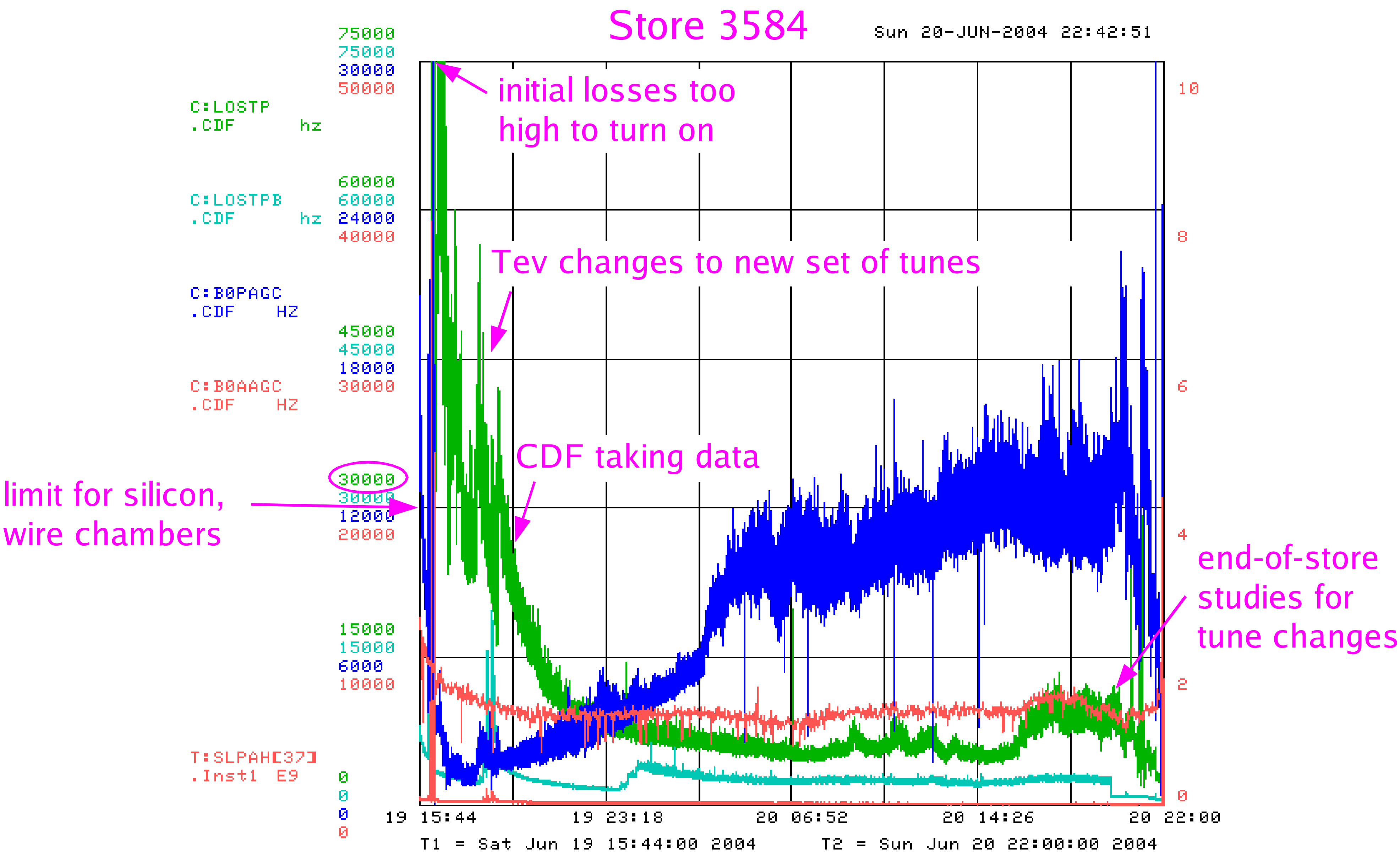
ACNET

LOSTP, LOSTPB
- fast feedback (<1 Hz)
- total losses only

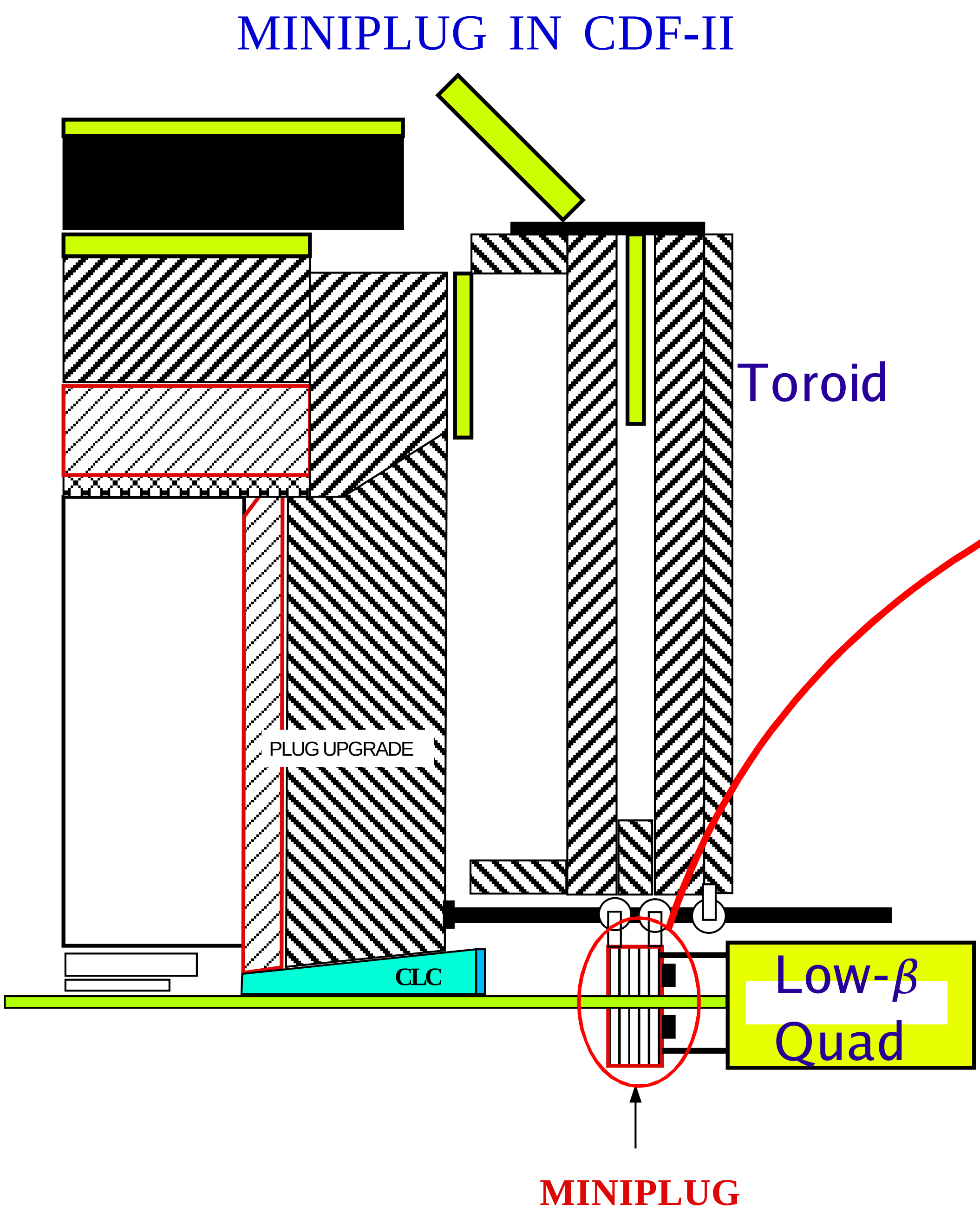
B0PLOS, B0ALOS
- slow feedback (~7 Hz)
- both total and bunch-by-bunch losses



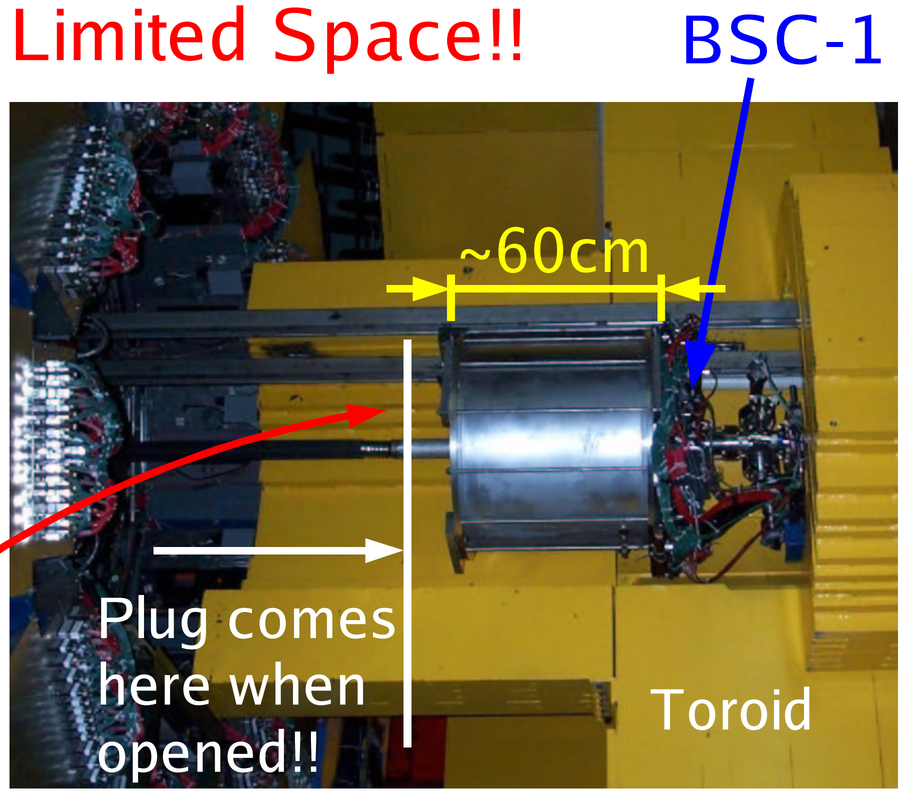
Beam Loss Measurements



MiniPlug Calorimeters

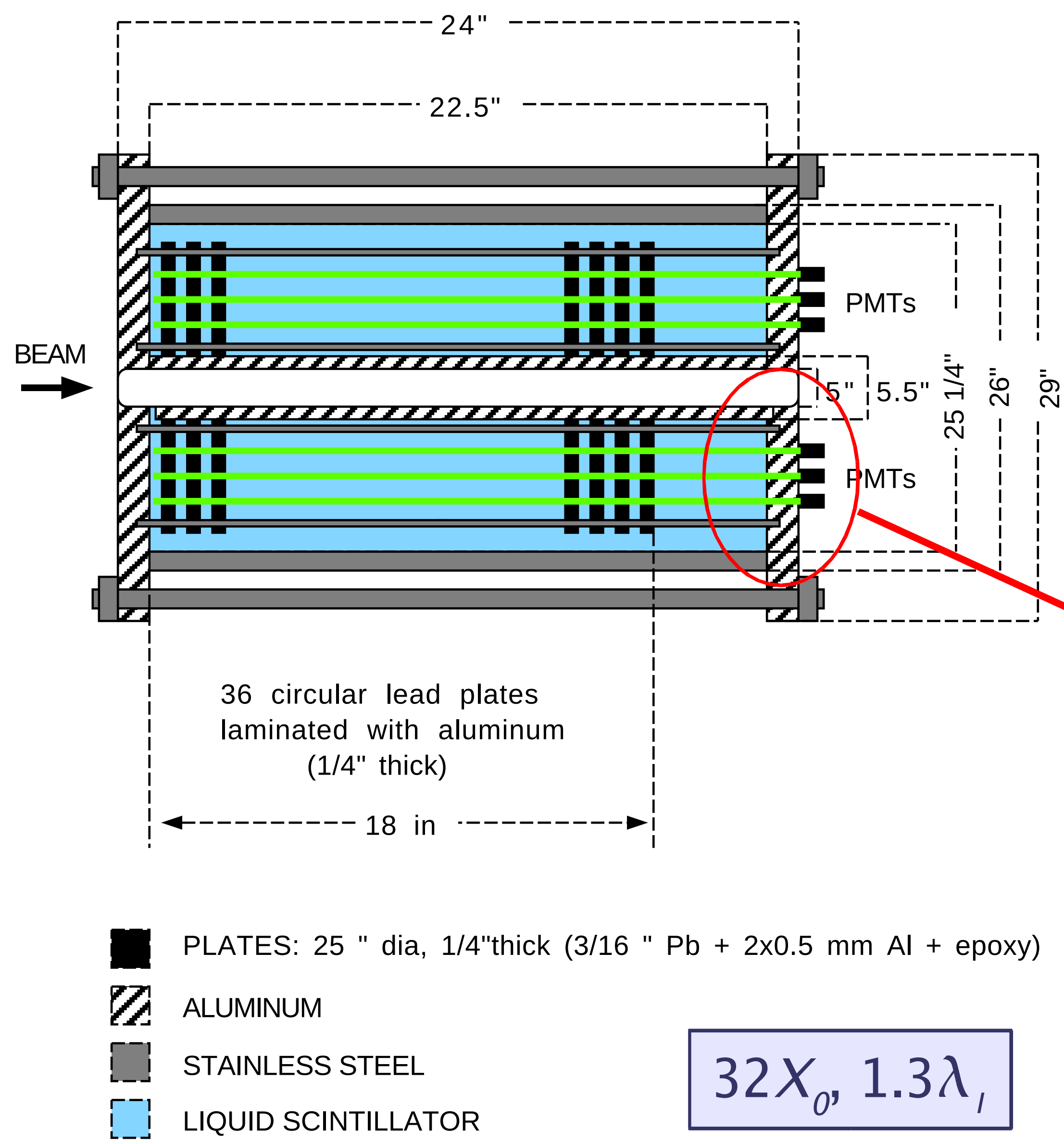


Limited Space!!



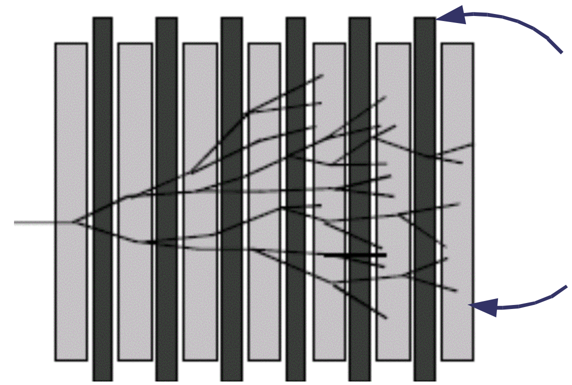
$3.7 < |\eta| < 5.2$

MiniPlug Calorimeters



$$32X_0, 1.3\lambda_I$$

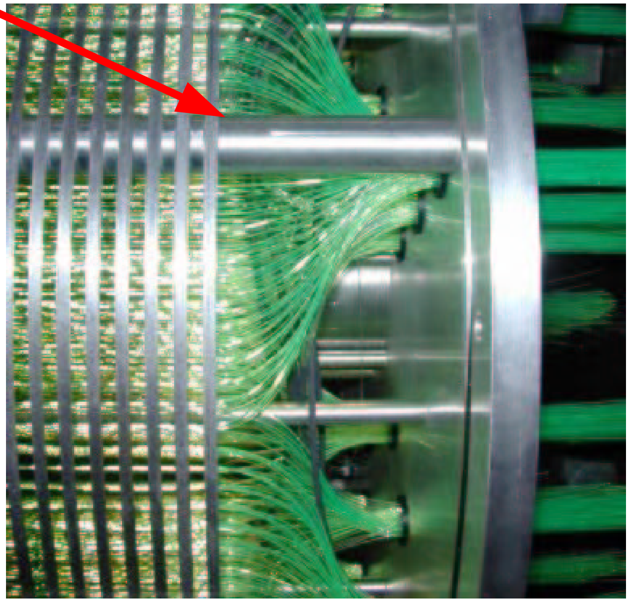
Sampling Calorimeter



Detector: Liquid Scinti. (BC-517L)

Absorber: Pb + 6% Sb

Read out by wavelength shifting fibers (Kuraray Y11)

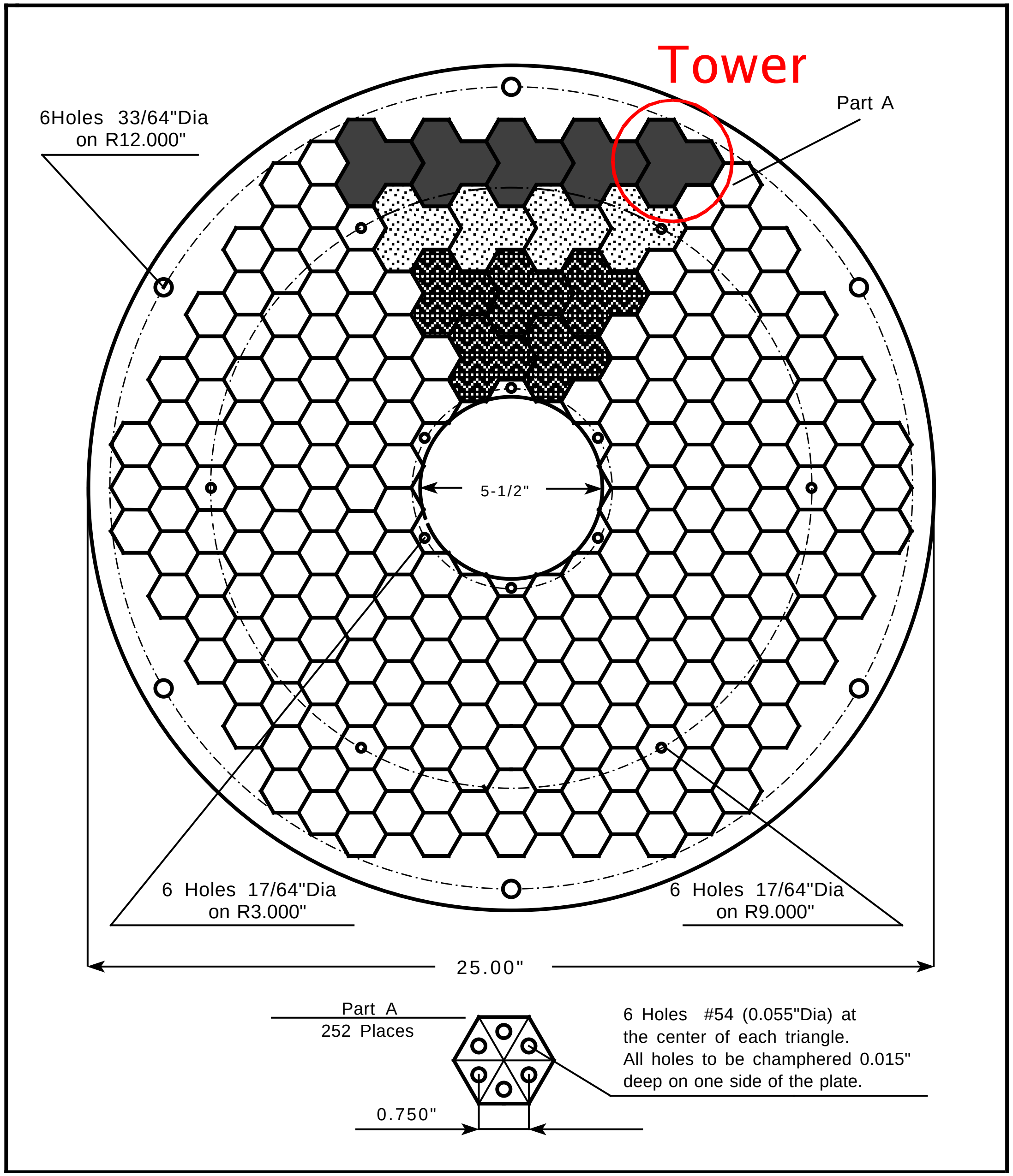


MiniPlug Design

Electromagnetic calorimeter with hadron detection capability

"Boundary-less" Structure

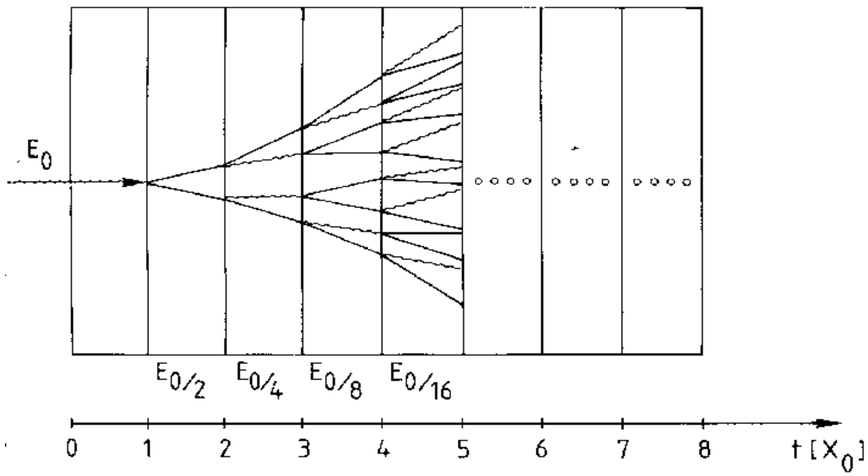
- A "hexagon" holds 6 WLS fibers
- 3 hexagons form a readout unit ("tower")
- 84 towers and 18 last dynodes ("sum-towers") per detector



Electromagnetic Showers

Simple Model at High Energy

- bremsstrahlung and pair creation only
- $X_0 = \lambda_{pair}$



$$N(t) = 2^t \rightarrow E(t)^{particle} = E_0 / N(t) = E_0 2^{-t}$$

Shower process continues until $E(t)<E_c$ (critical energy)

$$N^{total} = \sum_{t=0}^{t_{max}} 2^t \approx 2\frac{E_0}{E_c}$$

Longitudinal shower development

- shower maximum : $t_{max} = \ln\left(\frac{E_0}{E_c}\right)\frac{1}{\ln 2}$
- 95% containment : $t_{95\%} \approx t_{max} + 0.08Z + 9.6$

Transverse shower development

95% containment in a cylinder with radius R_M (Molière radius)

$$R_M = \frac{21 MeV}{E_c} X_0 \quad [g/cm^2]$$

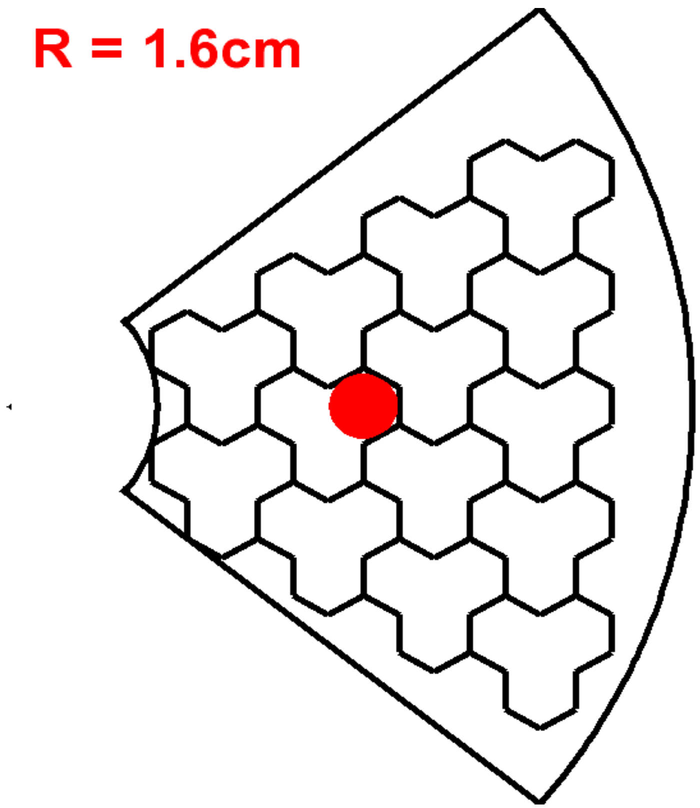
E_0=100 GeV electron into MP (=$32X_0$)

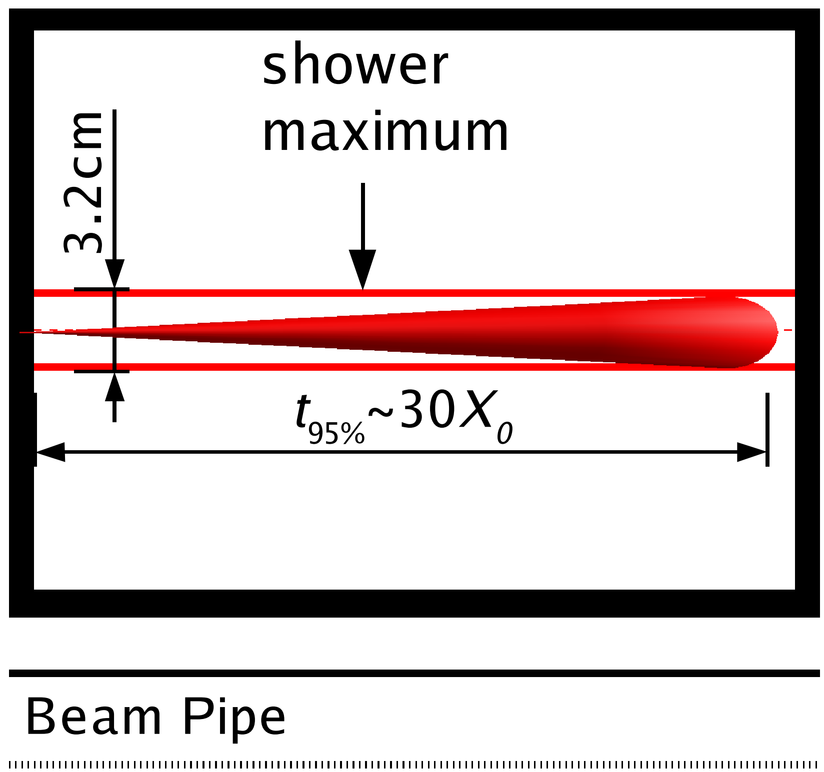
⇩

$t_{max} \approx 14X_0$, $t_{95\%} \approx 30X_0$, $R_M \approx 1.6$cm

Electromagnetic Showers in MiniPlug

100 GeV electron shower

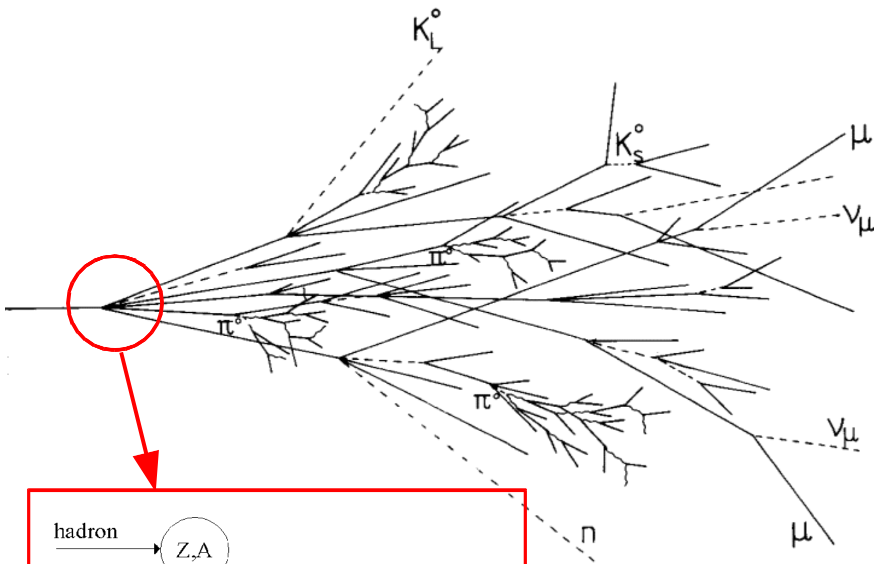


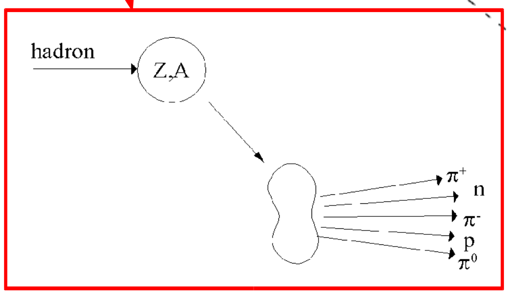


Transverse size of shower ≈ size of a hexagon

>95% energy of (e, γ) with up to 500-1000 GeV absorbed

Hadronic Showers





$N^{particle} \propto \ln(E)$

$p_T^{particle} \approx 0.35\, GeV/c$

Longitudinal shower development

- shower maximum : $t_{max} \approx 0.2 \ln(E) + 0.7$
- 95% containment : $t_{95\%} \approx a \ln(E) + b$
  $a=9.4, b=39 (Fe)$

Transverse shower development

95% containment in a cylinder with radius λ_I

$$\lambda_I = \frac{A}{N_A \sigma_{total}} \approx 35\, A^{1/3} \quad [g/cm^2]$$

- ✔ Inelastic nuclear interactions
- ✔ various processed involved

large energy fluctuations

➔ MiniPlug : E_T resolution ~ 40 %

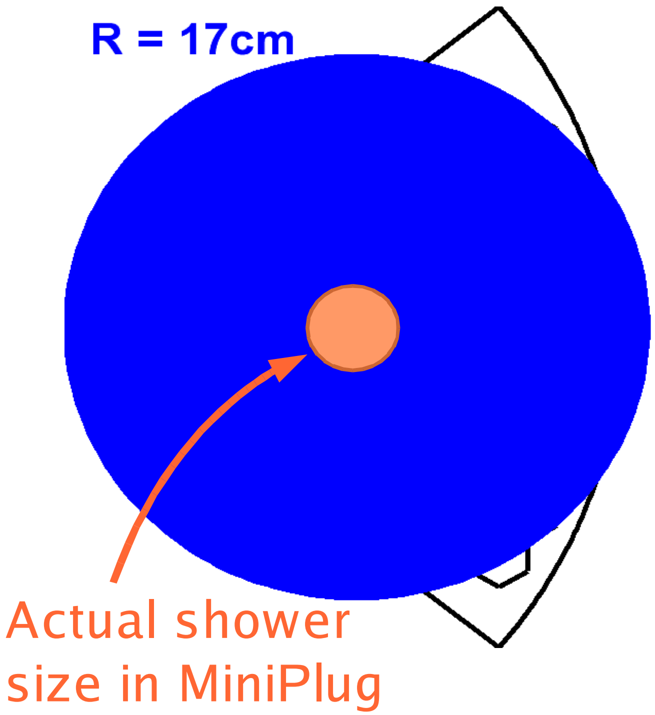
E_0=100 GeV $\pi^\pm$ into MP (=1.3λ_I)

⇩

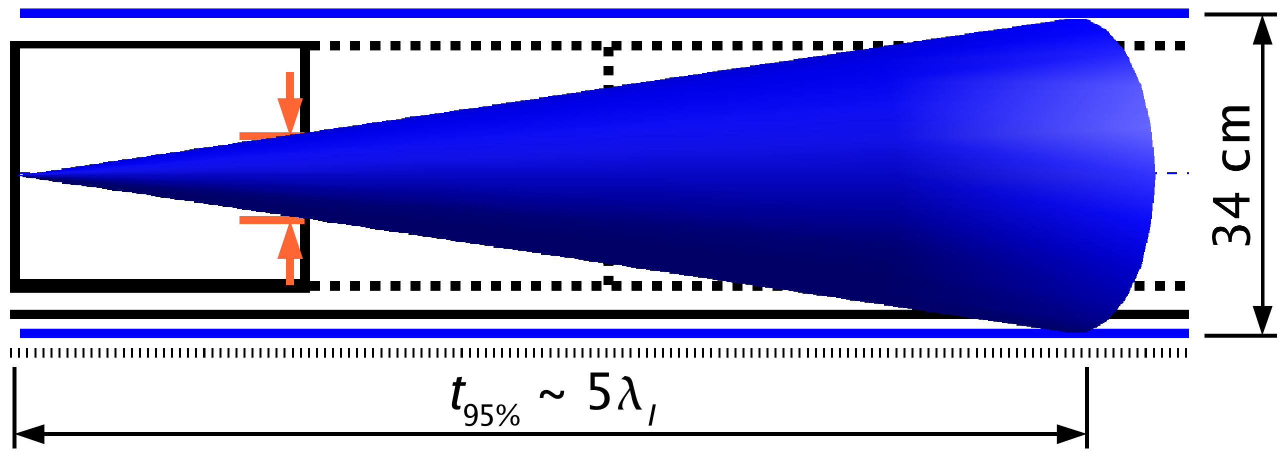
λ_I(Pb)=17cm, $t_{max} \approx 1.6\lambda_I$, $t_{95\%} \approx 5\lambda_I$

Hadronic Showers in MiniPlug

100 GeV hadronic shower



Transverse size of shower ≈ MP size if length of MP is ~ $5\lambda_I$

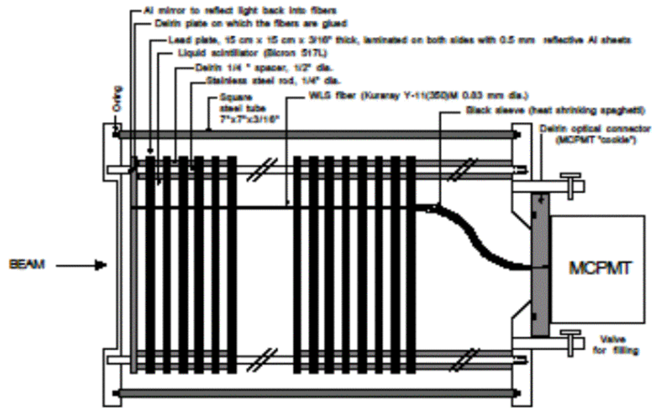


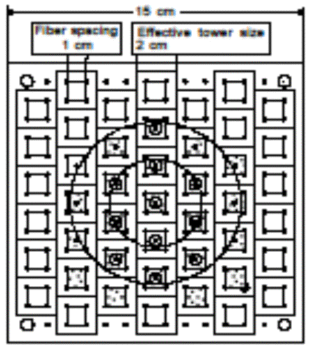
Energy resolution for hadronic shower is about 40%

Good position resolution is retained by detecting hadrons before they make (big) showers

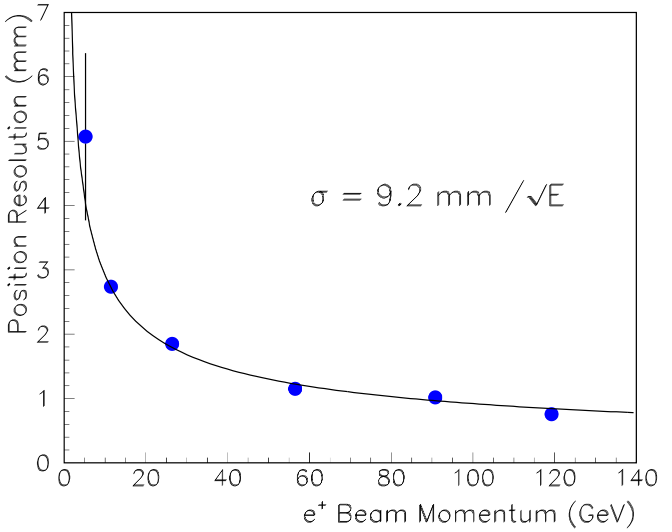
Energy and Position Measurements

MiniPlug prototype ($28X_0$, $1\lambda_I$)

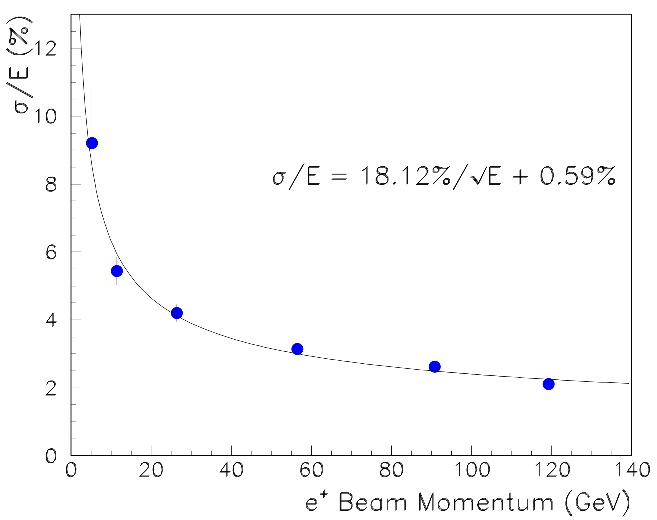




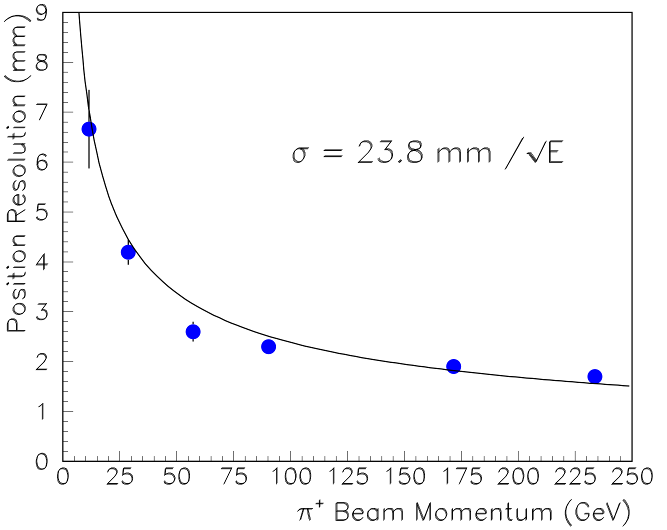
Positron position resolution



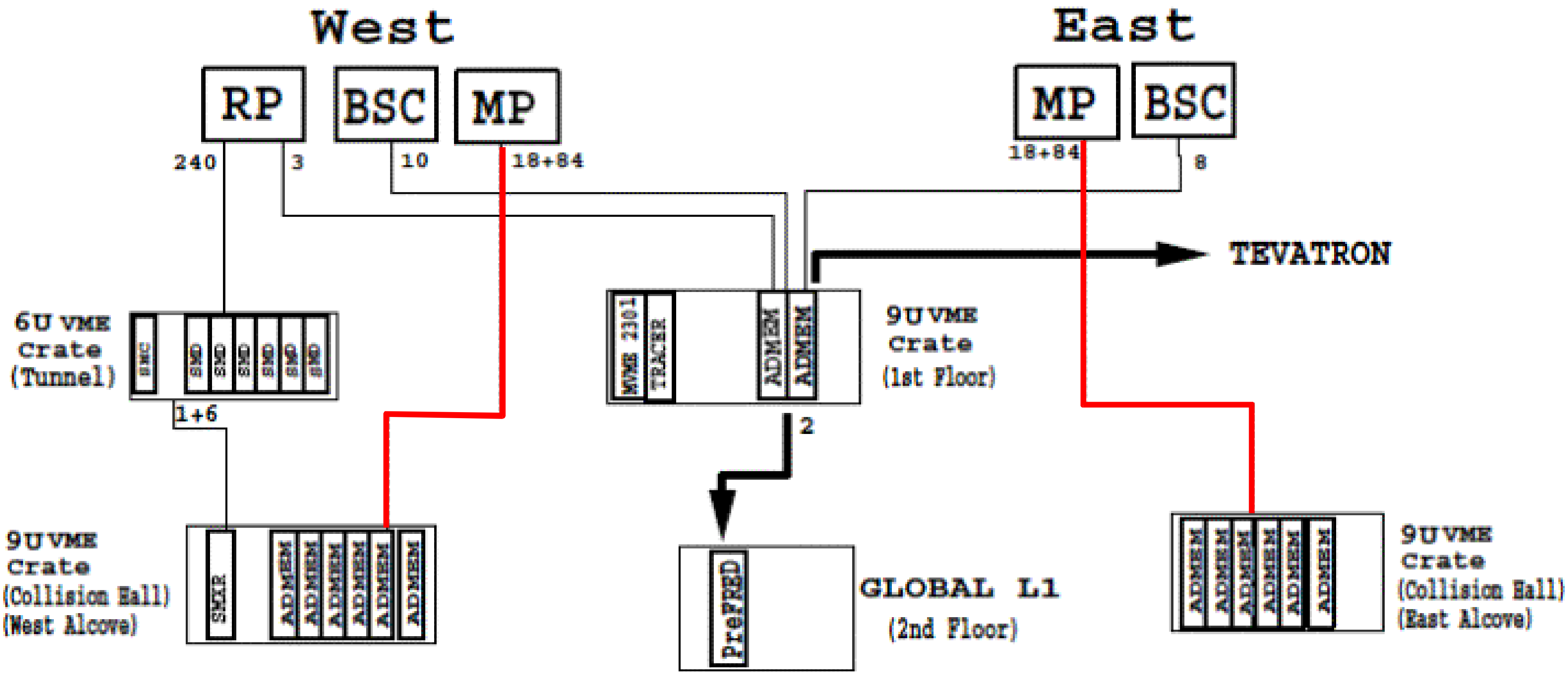
Positron energy resolution



Pion position resolution



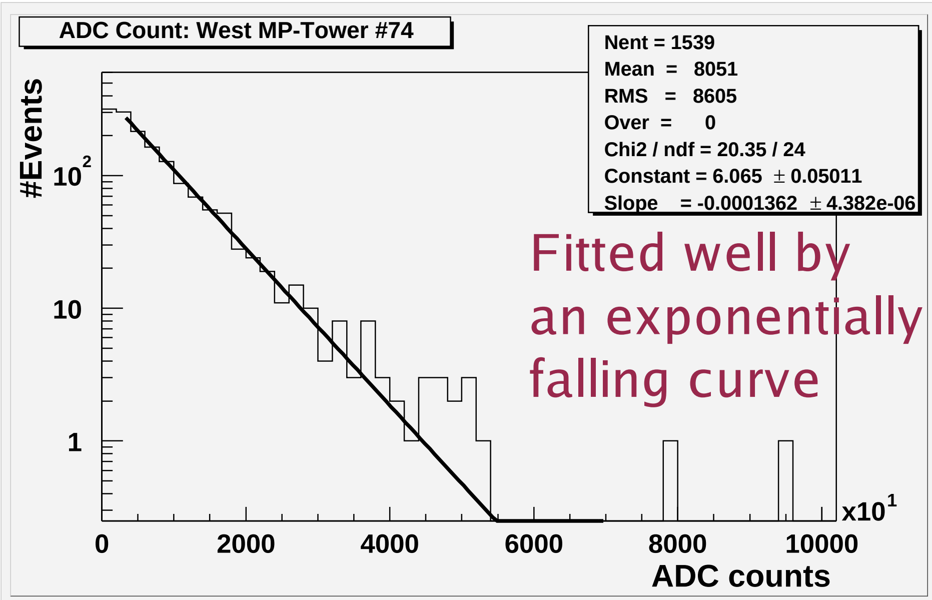
Readout Electronics

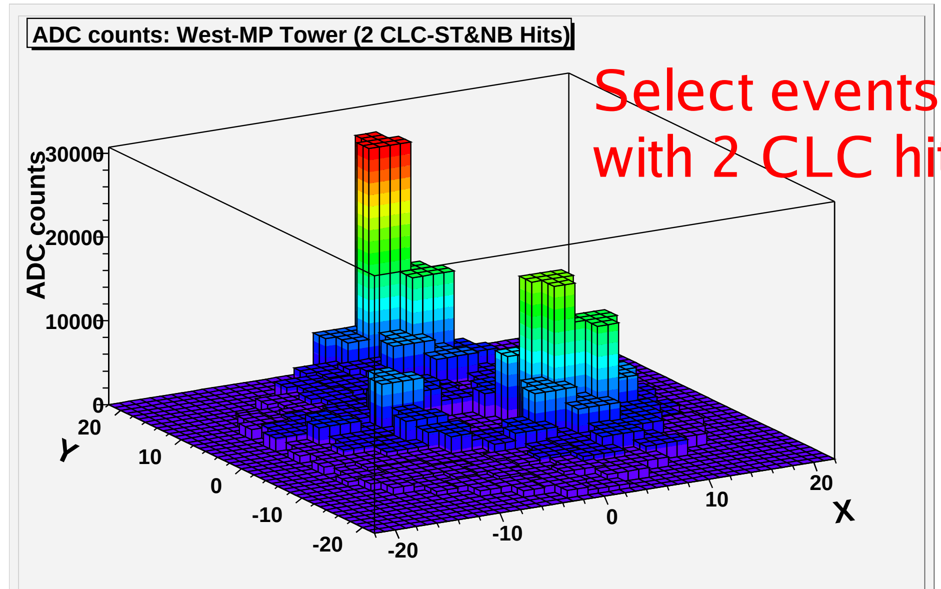


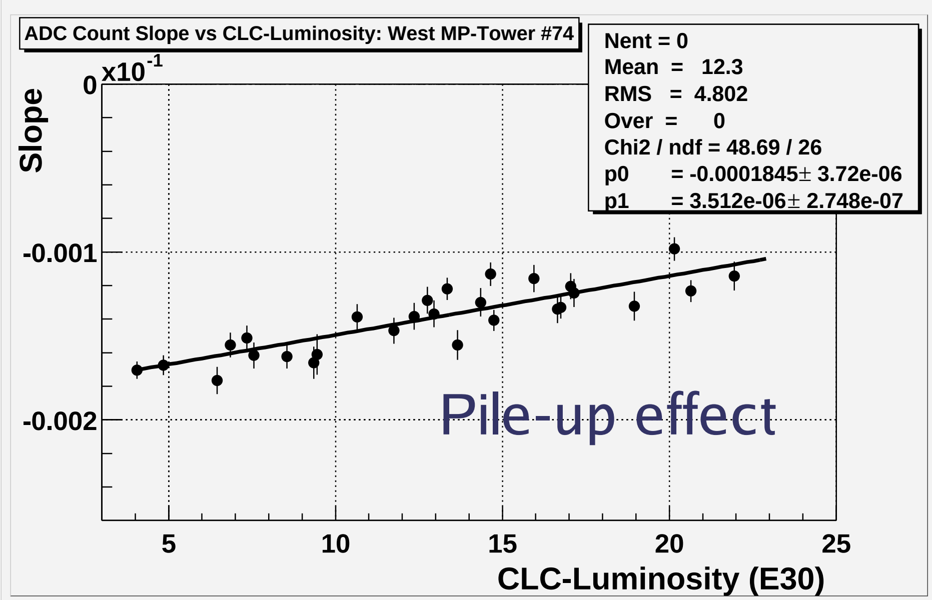
2x84 "tower" and 2x18 "sum-tower" signals delivered to 12 ADMEMs in FCAL_00 and 01 VME crates in the collision hall

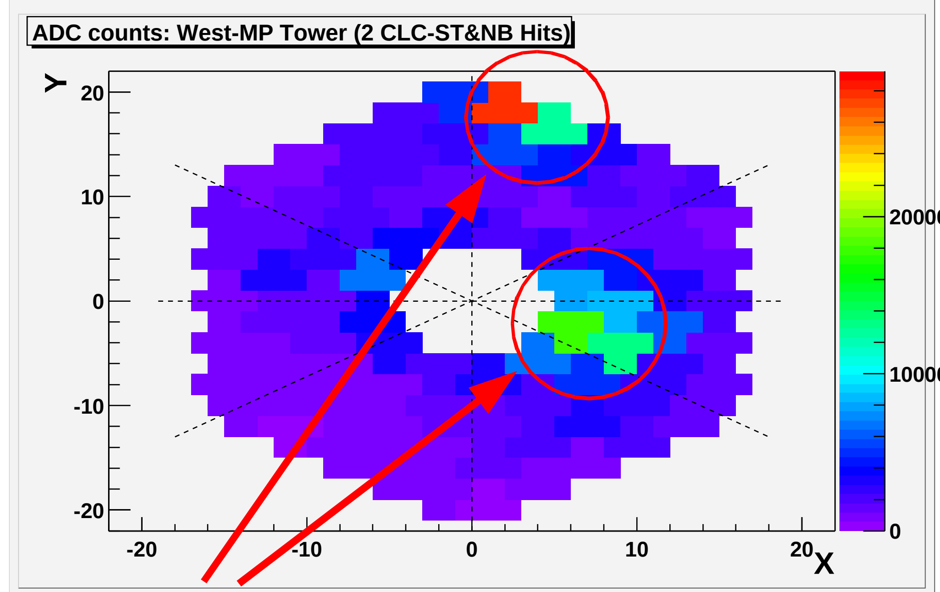
"sum-tower" signals will be used for the trigger

Digitized Signal









Hadrons ~ Tower size

Energy Calibration Using MC Simulation

Monte Carlo based calibration (cross-check with data)

MBR (Minimum Bias Rockefeller) developed to generate
- elastic scattering,
- single and double diffraction,
- hard core events

tuned to simulate charged and total multiplicity, p_T and η distributions

Approximate MiniPlug detector simulation:

π^0 : all energy is deposited

$\pi^\pm$: 70% of time, taken from Gaussian $\mu = E(\pi^\pm)/3$, $\sigma = \mu/2$

30% of time, taken from Landau (peak=0.5 GeV, width=0.125 GeV)

➔ Energy deposited in MiniPlug $\simeq$ 40-50% of true particle energy on average

Energy Calibration : Data vs Simulation

Step 0: particle deposit energy in simulation

$E_{\text{particle-deposited}}$ (simulation)

Fit to $exp[-A_{\text{particle-deposited}}(sim) \times E]$

Step 1: minimize tower-by-tower variation

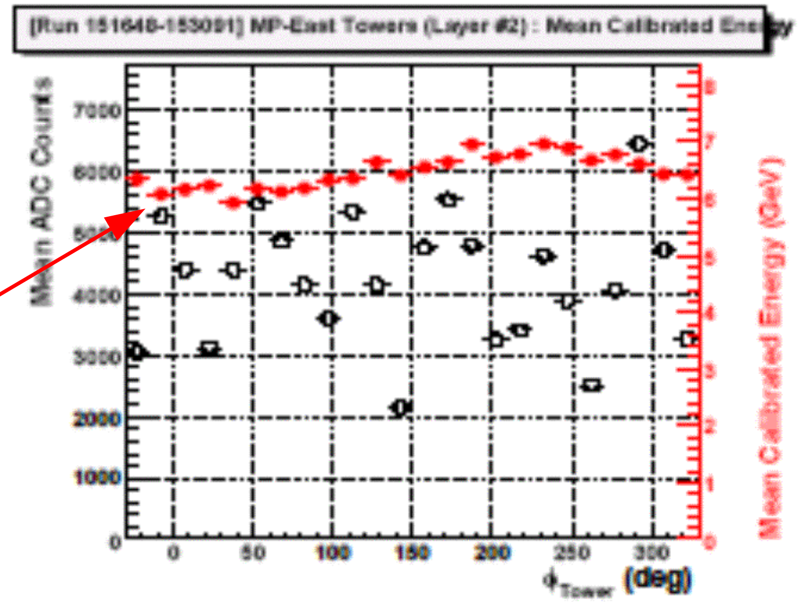
ADC_{tower} (data) → Fit to $exp[-A_{\text{tower}}(data)X]$

⇩

$C = A_{\text{tower}}(data) / A_{\text{particle-deposited}}(sim)$

⇩

$E_{\text{tower}}(data) = ADC_{\text{tower}}(data) \times C$



Step 2: data-MC comparison

Find seed tower(s) using $ET_{\text{tower}}(data)$

⇩

$ADC_{\text{seed tower}}$ (data)

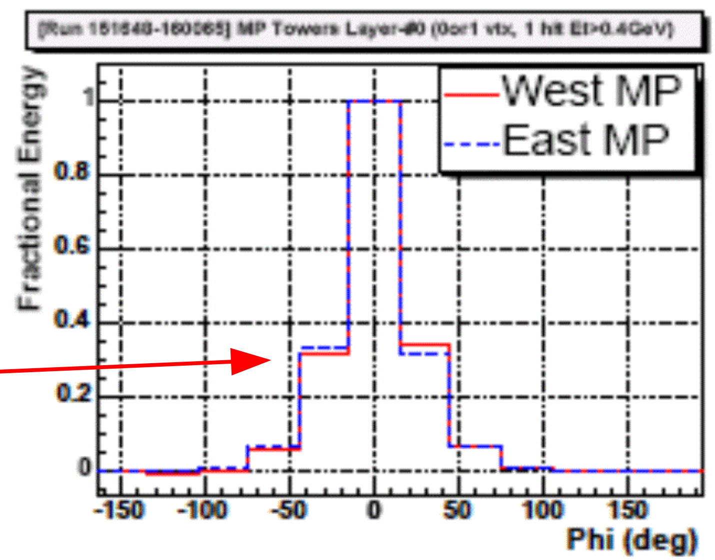
→ Fit to $exp[-A_{\text{seed-tower}}(data)X]$

⇩

$A_{\text{seed-tower}}(data)$ → $A_{\text{particle-deposited}}(data)$

⇩

$C_{\text{calib}} = A_{\text{particle-deposited}}(data) / A_{\text{particle-deposited}}(sim)$

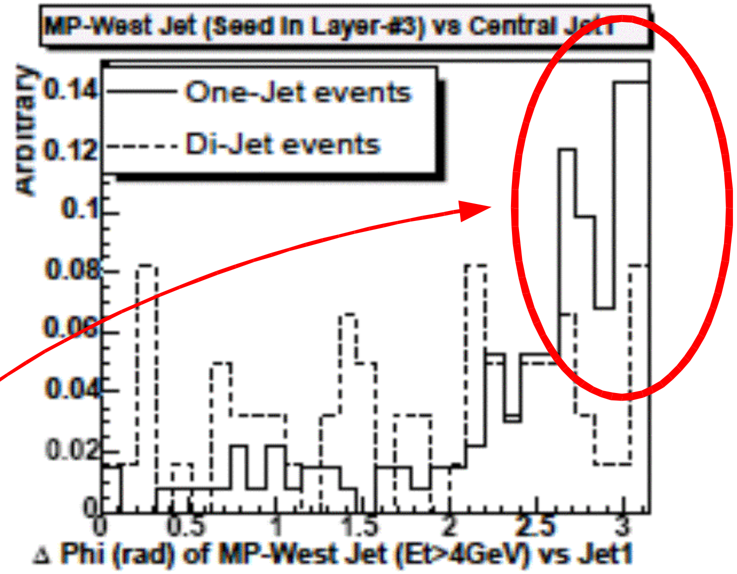


Energy Calibration Using Dijet Balance

Cross-check with dijet balance

E_T balance between central jet and "MiniPlug jet"

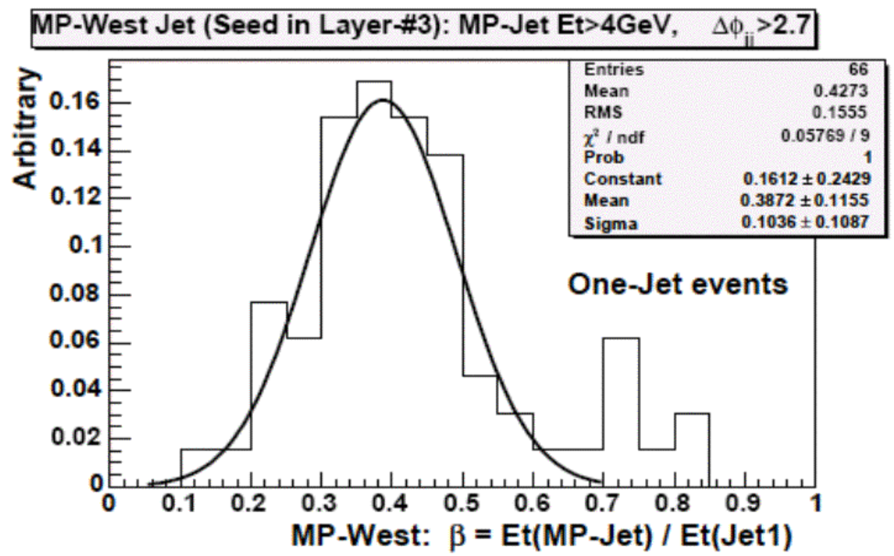
- only one central jet: (E_T>5 GeV, 0.1<$|\eta|$<0.7)
- no jets in Plug



$\Delta\phi \approx \pi$ → second jet in MiniPlug

$\beta = E_T(\text{MP Jet}) / E_T(\text{Central Jet})$
$= 0.4 \pm 0.1$

⇨ consistent with approximate detector simulation



Summary

Coverage
- Rapidity Gaps
- Forward Particles/Jets

→ BSC : $5.5 < |\eta| < 7.5$

→ MiniPlug : $3.7 < |\eta| < 5.2$
- Cover from edge of Plug down to the beam pipe

Resolution
- Segmentation
- Longitudinal Depth

→ MiniPlug designed to have good position resolution for hadrons (as well as e/γ)

Environment
- Radiation
- Space Limitation

→ Adopt radiation hard technology studied at SSC/LHC environment

→ Replace damaged BSC counters as necessary

→ Best use of limited space!

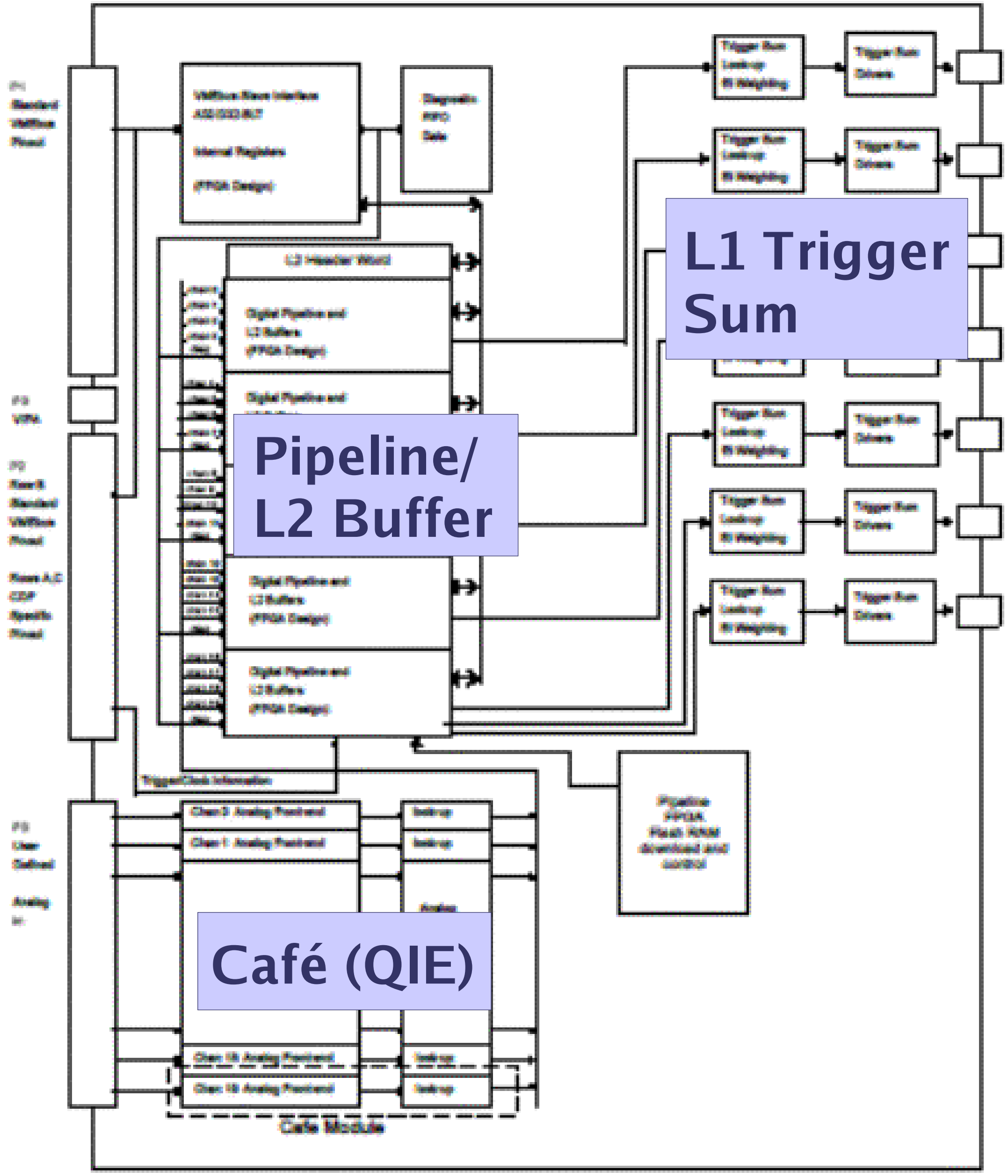
ADMEM

- Digitize wide dynamic range of charge signals to a specified precision
- “Deadtime-less” operation at every bunch crossing (132 ns)

QIE (Charge Integrator and Encoder)
- divide signal into multiple ranges
- integrate fractional charge in each range
- linearize charges in FRAM look-up table

Pipeline/L2 Buffer :
- Store digitized data in pipeline
- Move data to L2 buffers with L1 trigger accept

Trigger Sum :
- provide signal sums to trigger



Luminosity from BSC-1

E*W Coincidence Rate

$R_{E*W}[Hz] = L_{inst}\ [Hz/mb] \cdot \sigma\ [mb] \cdot \epsilon$

L_{inst} : Instantaneous luminosity

σ : *pp* total cross section

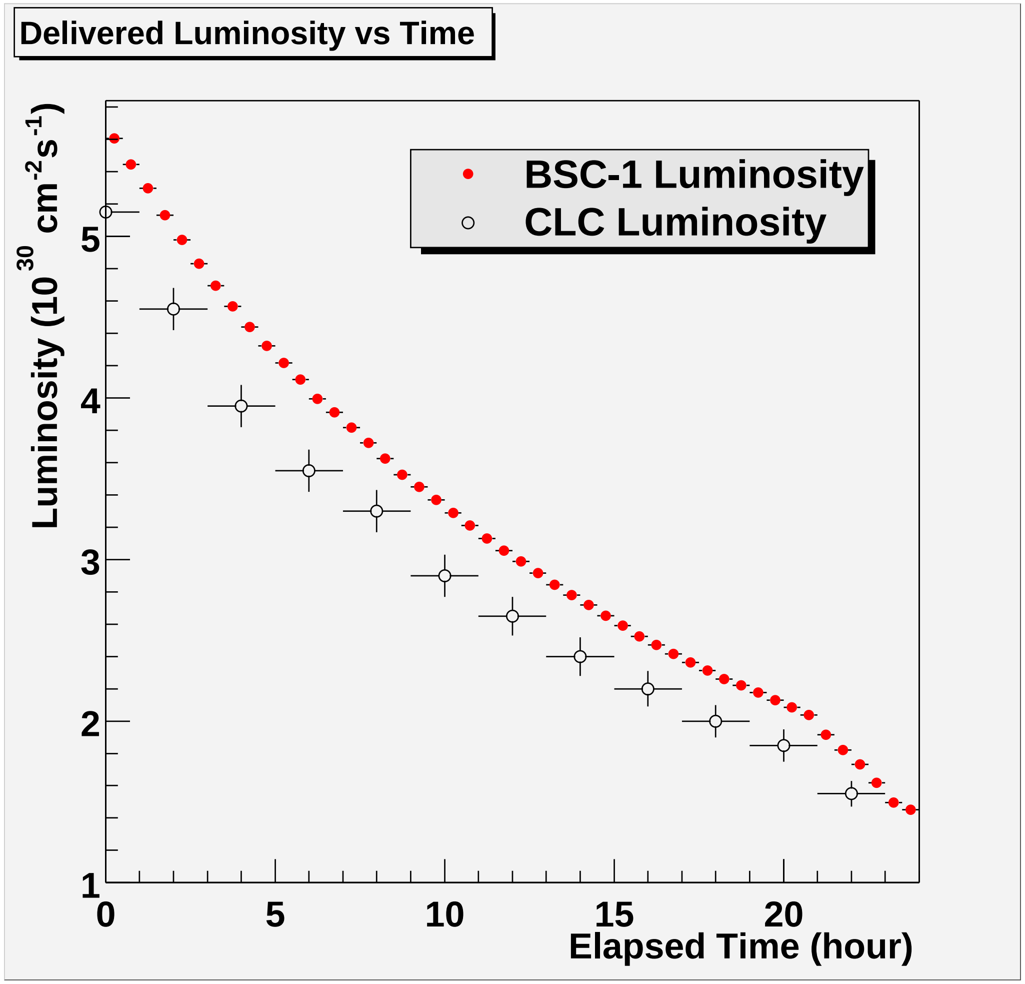
ϵ : BSC-1 acceptance

$\sigma \cdot \epsilon$ = 25.6 mb

PRD 50, 5550 (1994)

BSC-1 measured luminosity is close (within 10 %) to CLC luminosity

Need more studies on acceptance



Calorimetry Basics

Energy measurement by total absorption

Formation of electro-magnetic, or hadronic showers

Works for both
- charged ($e^{\pm}$, hadrons) and
- neutral (n, γ) particles

Charged particle interactions:
- ✔ ionization $p + atom \rightarrow p + atom^{+} + e^{-}$
- ✔ bremsstrahlung $e\ (+\ nucleus) \rightarrow e + \gamma$

Photon interactions:
- ✔ photo-electric effect $\gamma + atom \rightarrow atom^{+} + e^{-}$
- ✔ Compton scattering $\gamma + e \rightarrow \gamma' + e'$
- ✔ pair creation $\gamma\ (+\ nucleus) \rightarrow e^{+} e^{-}\ (+\ nucleus)$

At high energy, bremsstrahlung and pair creation are dominant